WHERE TO FLARE?

The following paper has been submitted by Captain David Jacobson. Captain Jacobson was invited by the Insititution of Engineers, Australia to present his paper to the 1987 Australian Aviation Symposium held in Canberra, 18-20 November 1987. Invitations of this nature are not made lightly, and for this he is to be complimented.

A limited assessment of the flare technique was carried out in our A300 and B727 simulators and in our aircraft by a group of supervisory pilots. These tests confirmed that the point of flare determined by this method approximated the initial flare height normally flown by these pilots. It has been reported that tests conducted by instructors more closely associated with ab-initio instruction have reached the same conclusion.

However, Flight Standards Management opinion is that this technique should not be used as a stand-alone determinent for the initiation of flare; but be borne in mind as an aid in the event of a pilot being unable to determine an acceptable flare height. A requirement of this nature is more likely during ab-initio flying training and in general terms the appropriate flare height for a particular type, once recognised by a pilot is reproducible within acceptable tolerances.

For those pilots who do find this technique of assistance, care should be taken not to exclude those peripheral visual cues which normally assist recognition of the correct flare height. In certain visual conditions the impact point on which the flare is initiated may be obscured due to wet runway conditions, glare on the runway surface from CAT 2 touchdown zone lighting, rain on the windshield at night and in some areas of the world, even a light layer of snow on the runway.

Instructor pilots should take care not to impose this concept on pilots whose flare height determination is already satisfactory.

Ray Baker, Flight Standards Manager.

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.

$\triangle$ Aim:	The distance on the landing surface from the touch point to the aim point.
$\triangle$ Flare:	The distance on the landing surface from the touch point to the aim point.
Main-wheel path:	The distance on the landing surface from the aim point to the flare cut-off point.
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_x, 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.
$\triangle$ X:	Distance on landing surface between the aim and impact points.
x_1, x_2:	Component lengths of $\triangle$ X.
Y(gamma):	Flight path angle, from horizontal.
K(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 qualification 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.

1

LONGITUDAL FIX V/S VERTICAL PERCEPTION
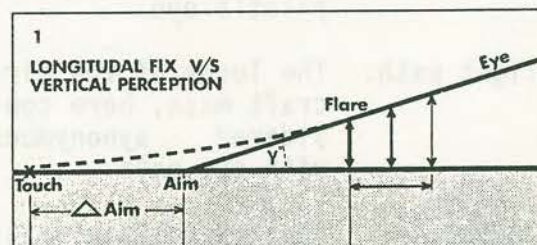
Much has been written on the subject of the aim point being the centre of expansion of a flow pattern, providing the pilot with a visual illusion as points surrounding the aim point accelerate radially outwards as the aircraft approaches the ground (motion parallax). Points beyond the aim point will 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.
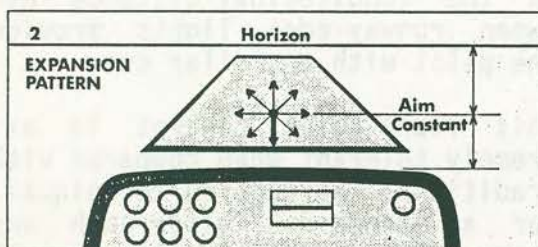
If such a point were selected and could be simply identified, a consistent longitudinal fix for the flare point for a given aircraft would be obtained as this pre-selected point appeared to move down the windshield (due to increasing depression angle) to the point where it reached the lower cut-off angle (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.
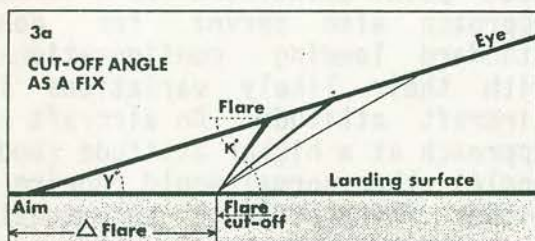
Calculation of this distance from the aim point to the flare cut-off point. ($\triangle$Flare), involves energy/geometry considerations, quickly determined in practice with experience, but complicated to derive by analysis.

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 ($\triangle X$) has provided suitable quantification for the flarepoint estimate. This distance accommodates the critical variables of glide angle (Y^*), 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.

3b
CUT-OFF ANGLE AS A FIX
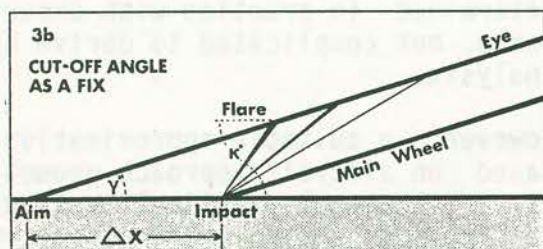
Appendix A (page 21) details the simple geometry involved, together with mathematical derivations of relevant formulae. The distance between the aim and impact points (X) is expressed as:

$$\triangle X = y_h \cot Y + x_2 \qquad (1)$$

Or, as a practical rule-of-thumb:

$$\triangle X = (y_h \frac{60}{Y}) + x_2 \qquad (2)$$

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

$$\triangle X = (y_h \frac{60}{Y}) - x_2 \qquad (3)$$

Note that for a standard glide path of 3°

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

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:

$$Y_e = \frac{\triangle X}{(\cot Y - \cot K)} \qquad (4)$$

The next important step is to locate the calculated impact point on the landing surface, short of the aim point. Many aviation authorit-
18.

ies 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, longitudinaly. 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, $\triangle X$, 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 instructor, 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. ☐

A SHORT COURSE
IN HUMAN RELATIONS

The six most important words:

I ADMIT I MADE A MISTAKE

The five most important words:

YOU DID A GOOD JOB

The four most important words:

WHAT IS YOUR OPINION

The three most important words:

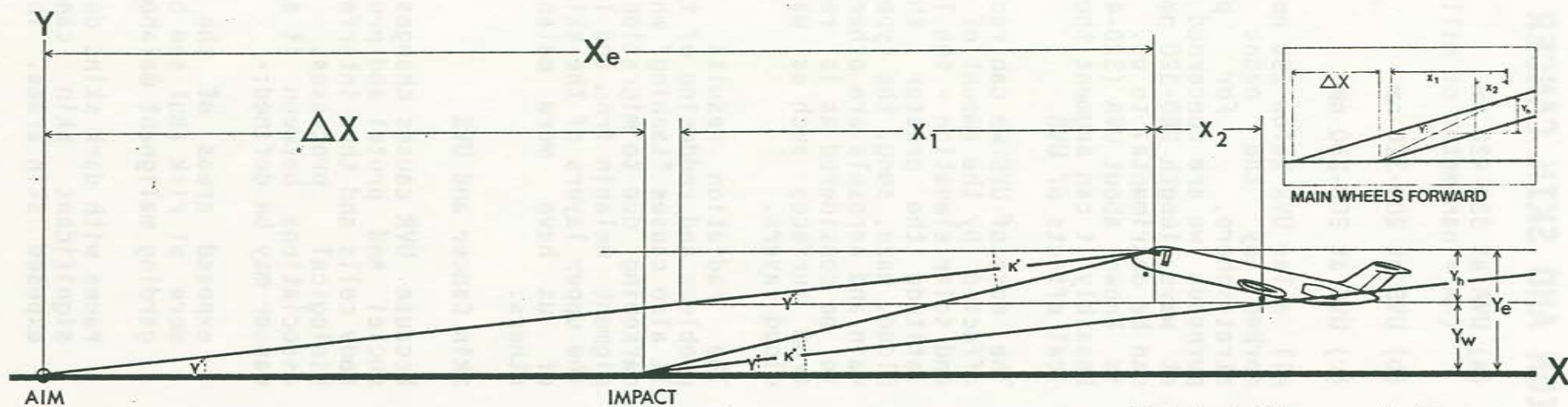## IF YOU PLEASE

The two most important words:

THANK YOU

The one most important word:

WE

The least important word:

I

NOTE: Aircraft attitude exaggerated for clarity.

1. SOLVING FOR ΔX:

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

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

$\therefore x_1 = y_h \cot \gamma'$

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), $\cot \gamma' = \dfrac{60}{\gamma'}$

Then $\Delta X = (y_h \times \dfrac{60}{\gamma'}) + x_2$ (2)

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

$\Delta X = (y_h \times \dfrac{60}{\gamma'}) - x_2$ (3)

2. SOLVING FOR Y_e:

From above, since,

$\cot \gamma' = \dfrac{\Delta x + (X_e - \Delta x)}{Y_e}$

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

and,

$\cot \kappa' = \dfrac{X_e - \Delta X}{Y_e}$

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

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

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

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

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

APPENDIX A