An Exploratory Investigation into the Definition of Tracking Standards for IFR Helicopter Approaches to Reduced Minima

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Abstract

An in-flight evaluation using the IAR Airborne Simulator was conducted to determine the magnitude of tracking errors which could be tolerated at decision height for a steep decelerating instrument approach to reduced minima in a helicopter. Handling qualities evaluations revealed a tradeoff between allowable height and speed errors, the reasons for which are still being examined.

Introduction

Background

The Flight Research Laboratory (FRL) of the Institute for Aerospace Research (IAR) (formerly the National Aeronautical Establishment (NAE)), National Research Council of Canada has been actively engaged in jointly funded experiments with the United States Federal Aviation Administration (FAA) since early 1980. These experiments, designed to address rotorcraft handling qualities requirements for flight under Instrument Flight Rules (IFR), have been performed under a Memorandum of Agreement with the FAA, AIA-CA-31. References 1 and 2 describe some of the previous phases of this program.

One of the major areas of investigation in the joint program with the FAA has been the operational feasibility of steep (6 degrees and above) decelerating instrument approaches to a decision height of 50 feet coincident with 20 knots groundspeed. During these studies it became apparent that the conventional standards of approach performance (also described as allowable flight technical errors) could not be extrapolated to the 50 foot decision height case. The approach tracking standards which allow an acceptable transition to visual flight and manoeuvring to a landing pad hover from the 50 foot decision height form an underlying constraint to the reduced minima approach concept.

Aim And Scope

The overall objective of the tracking standards program was to provide a systematic data base upon which the standards for satisfactory tracking performance of decelerating instrument approaches to reduced minima can be based. These standards, of course, would also be used in follow-on research regarding these reduced minima operations. The aims of the preliminary phase of the program were threefold; first, to determine the experimental approach for producing a tracking standards data base; second, to evaluate the approximate magnitude of errors in height from a nominal glideslope, and speed errors from a nominal deceleration profile, which would be acceptable at breakout for the transition to the visual approach to landing; and third, to examine some of the variables which govern the level of these acceptable errors.

Because of the preliminary nature of this program, tests were concentrated on a nominal glideslope of 9 degrees, with a brief investigation carried out on a nominal glideslope of 6 degrees. Furthermore, on the majority of approaches the breakout at decision height was to good visual conditions, with only a limited number of data points achieved in degraded visibility. Also, the approach and landing pad marking was of an austere form, with no attempt made to provide variable intensity approach and landing area marking.

This report describes this first phase of the program with emphasis on the procedures used and some of the rationale behind the approach taken. The report also describes the preliminary results of the evaluations.

The Airborne Simulator

Experiments were carried out using the IAR Airborne Simulator (formerly the NAE Airborne Simulator), an extensively modified Bell 205A-1 with special fly-by-wire

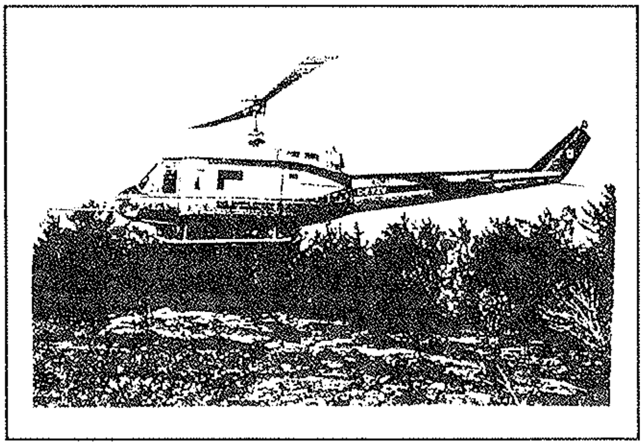

Figure 1 The IAR Airborne Simulator

capabilities that have evolved over the last eighteen years (Figure 1). The standard hydraulically boosted mechanical control actuators on this aircraft incorporate servo-valves that can be positioned either mechanically from the left (safety pilot) seat or electrically by the aircraft computing system. Evaluation pilot (right seat) control inputs from either conventional cyclic and pedals or integrated side arm controllers (conventional controls were used throughout this particular program) are measured and fed to a computing system consisting of two LSI 11/73, one Falcon microprocessor and other assorted hardware. Full authority fly-by-wire actuator commands are generated by software which manipulates inputs made by the evaluation pilot and data from a full suite of aircraft state sensors.

Additional modifications to the Airborne Simulator have been incorporated to increase the simulation envelope of the facility. The standard Bell 205 stabilizer bar was removed in order to quicken the control response of the teetering rotor system, and the mechanical cyclic-to-elevator linkage was replaced with an electro-hydraulic actuator, although the elevator remained fixed in a neutral position for this program. Reference 3 provides a detailed description of the Airborne Simulator.

In order to simulate the visual environment of instrument flight conditions, an IMC Simulator manufactured by Instrument Flight Research Incorporated, Columbia, S.C. was employed. The "simulator" consisted of goggles with lenses that incorporated liquid crystals to vary the lens opacity. These goggles were worn by the evaluation pilot and were adjusted to provide a narrow field of unobstructed view of the flight instruments with the remaining peripheral view highly obscured. An electrical input to the goggles, provided by the aircraft computing system, caused the obscured peripheral view to clear at 50 feet above ground level, coincident with the approach decision height.

Cockpit Display

On all approaches, primary approach information was displayed in a combined form on a light emitting diode (LED) matrix electronic attitude and direction indicator (EADI) as shown in Figure 2. The 5 inch by 5 inch display consisted of LED's organized into a matrix with a density of 64 x 64 pixels per square inch. Raw data displays of errors in localizer, glideslope, and speed were provided, as well as a three axis flight-director for the approach. Reference 1 details the design of the flight director. Warning of the decision height was accomplished by flashing the radio altitude box on the left side of the display and the flight-director command symbol. This flashing started when the aircraft was 10 feet above decision height, and remained flashing until decision height was reached.

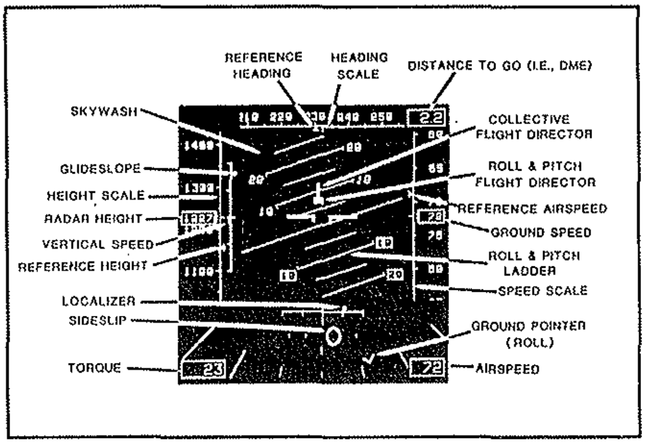

Figure 2 Format of Integrated IFR Display

In this program the errors in glideslope and/or speed desired for the experimental data base were obtained by feeding biases into the command signal for the flight director. The raw display accurately reflected deviations from the nominal glideslope and speed deceleration profile throughout the approach.

Control Characteristics and Stability Augmentation

The analogue control force feel system of the Airborne Simulator was set up to provide 1/2 lb breakout and 1/2 lb/in stick force gradient for the pitch and roll axes. A slow rate trim for pitch and roll was provided through a "coolie hat" switch on the cyclic control stick. No trim force release function was provided. The collective lever was a typical adjustable friction type with no force gradient or perceptible breakout force.

The yaw pedal force feel system was adjusted to provide just enough breakout and gradient forces to allow good self-centring of the pedals. Two yaw axis modes were available during the approach, a simple rate damped mode and a heading hold system. The heading hold mode completely eliminated the need for yaw pedal inputs during the approach.

In this experiment the Airborne Simulator was configured to represent dynamic characteristics of rotorcraft presently considered as a standard for instrument flight. For example, levels of pitch and roll rate damping similar to those of an augmented S-76 were incorporated. Figure 3 shows the effective overall rate damping derivatives implemented on the Airborne Simulator as a function of speed. For comparison purposes, the "SAS on" rate damping derivatives of the standard S-76 are also included on the figure. Inter-axis control coupling between all aircraft axes were essentially eliminated by the use of simple control cross feeds to the respective control axes. This characteristic is also similar to a fully augmented S-76.

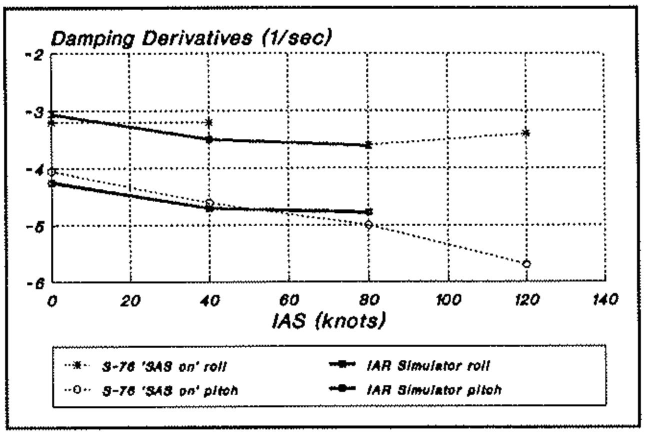

Figure 3 Damping Derivatives of the IAR Simulator

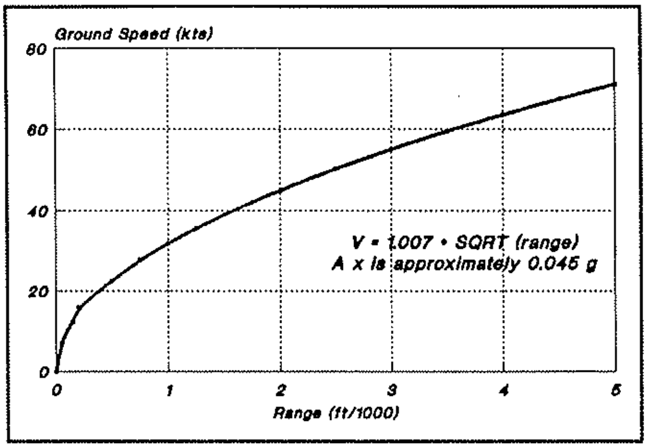

Figure 4 Approach Deceleration Profile

Approach Description

Steep (6 and 9 degree) decelerating instrument approaches were performed to a decision height of 50 feet by tracking a 3-cue flight director (localizer, glideslope and speed). On the majority of approaches, the evaluator tracked the flight director manually, although some approaches were flown with the aircraft coupled to automatically track the flight director in all three axes. As previously mentioned, the flight director command signal was altered on each approach to lead the aircraft to a desired error state at breakout while the raw data displays truthfully reflected the error condition.

Approach Guidance

The position measurements obtained from a multiple transponder system, smoothed with doppler ground speed information, were used as estimates of the aircraft position and used to provide approach guidance. Absolute accuracy of the horizontal position measurement using this system was on the order of 6 feet. Localizer and distance quantities were calculated by transforming the position information into the appropriate reference frame. Since the terrain in the approach area was relatively flat, radar altitude and distance from the touchdown zone were used to calculate glideslope position.

Deceleration Profile

All approaches were flown using ground speed calculated from a mixture of position, doppler ground speed and acceleration measurements. The desired approach speed was initially a constant controlled by a cockpit panel selector. When this constant speed and the aircraft range to the touchdown point intercepted the deceleration profile shown in Figure 4 the commanded speed became that of the deceleration profile. Both the commanded ground speed and actual aircraft ground speed were displayed on the EADI for the entire approach.

Landing Area

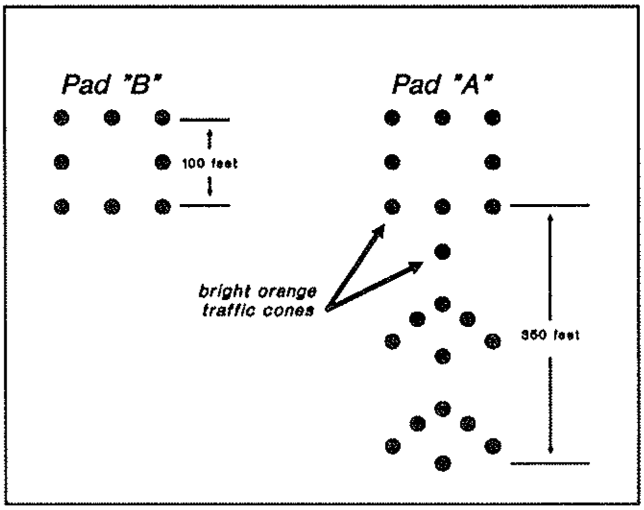

Figure 5 Landing Pad Markings

Approaches were flown to one of two landing pads located in an open field on relatively flat terrain. In most cases, this field was covered with snow, although blowing snow was not a factor in reducing visibility. The landing areas were marked with bright florescent orange traffic cones. Figure 5 depicts the two landing pads used in the experiment, differing only in the "lead-in" markings shown for pad 'A'.

Experimental Procedure

A preliminary series of ad-hoc evaluations for this program were flown by one of the project engineers and one research pilot. The objectives of these evaluations were to determine the experimental procedure for the more formal evaluations to come and to make preliminary judgements on the magnitudes of speed and glideslope errors that were practical for later, formal evaluations. On a number of these approaches it was found that the heading of the aircraft at breakout could override the effects of all other tracking errors since large deviations from the approach heading, in combination with some glideslope error values, resulted in the pad not being visible at decision height. To eliminate this possible confusion in formal evaluation data, the use of heading hold on the inbound approach heading was used for the remainder of evaluations. (The visual acquisition of the landing pad is an issue which must be considered carefully since each IFR rotorcraft has its own inherent field of view and visibility restrictions)

The ad-hoc evaluations also compared the workload of transition from breakout to landing pad hover following the manual tracking of the approach with that of flying an autopilot coupled approach. The discussions of this issue following the evaluation concluded that during the manual tracking approach the pilot was more "in-the-loop" and could more easily make the transition to visual flight but was less aware of the tracking errors present at breakout. The autopilot approaches with takeover to manual flight at the decision height allowed the evaluation pilot more time to scan the display and be aware of the tracking errors at breakout but did require additional effort to get "into the loop" of control. Since occasional errors in position measurement gave highly undesirable aircraft reactions during the coupled approach, the majority of formal evaluations were made using manual tracking of the flight director.

Formal evaluations were flown by four pilots, including three research pilots and one rotorcraft certification pilot from the FAA. Each of the evaluators was asked to manually track the flight director down to decision height where the goggles cleared, and then continue the approach to a hover over the landing area. Heading hold was engaged for all approaches, resulting in close alignment of aircraft heading to the approach course at breakout. (The possible influence of crosswinds while using heading hold mode on these approaches is discussed in Reference 1.)

On completion of each approach the evaluators were asked to rate the handling qualities and aircraft performance for the visual portion of the approach on the Cooper-Harper handling qualities rating scale and to supply comments regarding their ratings and the task in general. Post flight debriefing of all pilots was used to solicit more comments regarding the evaluations.

Evaluations were made over a wide range of glideslope and speed errors primarily for 9 degree approaches however some 6 degree approach data was also gathered. Additional evaluations were made of the effect of having the IMC goggles remain slightly fogged throughout the "visual" segment of the approach and requiring the evaluation pilot to land in this reduced visibility condition. It was hoped that these evaluations could somehow indicate the impact of actual conditions at breakout rather than the near-perfect visibility afforded by the clearing of the IMC goggles at decision height.

Evaluation Results

Acceptable Error Boundaries

Figures 6 and 7 are plots of the handling qualities ratings corresponding to the various error states evaluated for the 9 and 6 degree glideslope cases. For the majority of evaluations, each evaluator indicated that a handling qualities rating of 7 corresponded to an approach situation where the manoeuvres required or the time available to make the transition to visual flight was unacceptable. A rating of 6 therefore was indicative of an error state which was acceptable, although sometimes just marginally. This use of the Cooper-Harper scale may initially be perceived as significantly different from the standard interpretation since the 6-7 boundary describes whether "adequate performance is attainable with tolerable pilot workload". In general all evaluators in this program employed the strategy of limiting their flare attitude, collective commands and "quickness of response" to a level they perceived as acceptable for the transition manoeuvre. In cases where the evaluation pilots rated the transition as a 7 or above, these attitude, collective and response limits did not allow enough performance to stop the aircraft in the desired location, thus giving the "adequate performance is not attainable" result.

As shown in the two figures, especially in the 9 degree approach case, there is an envelope of acceptable errors at decision height for combinations of speed and height errors. A suggested envelope is drawn as a dashed line on Figure 6. Three unacceptable ratings were disregarded in the drawing of this boundary based on the pilot comments for each approach and ratings and comments of other approaches at similar error levels. A 6 degree approach envelope was determined by geometrically converting the 9 degree approach glideslope error boundary to values which correspond to the same physical position relative to the landing pad on a 6 degree approach.

Inside the acceptable- unacceptable boundary on Figure 6 is a second boundary (a solid line) suggesting the maximum error level which still would produce Level 1 handling qualities ratings (a value of 3 or less). This second area is that in which the transition and manoeuvring after breakout were described as "satisfactory without improvement", clearly a desirable envelope to aim for in flight director design and general operations but not the envelope of maximum allowable error. Again this boundary was geometrically converted to the 6 degree glideslope case.

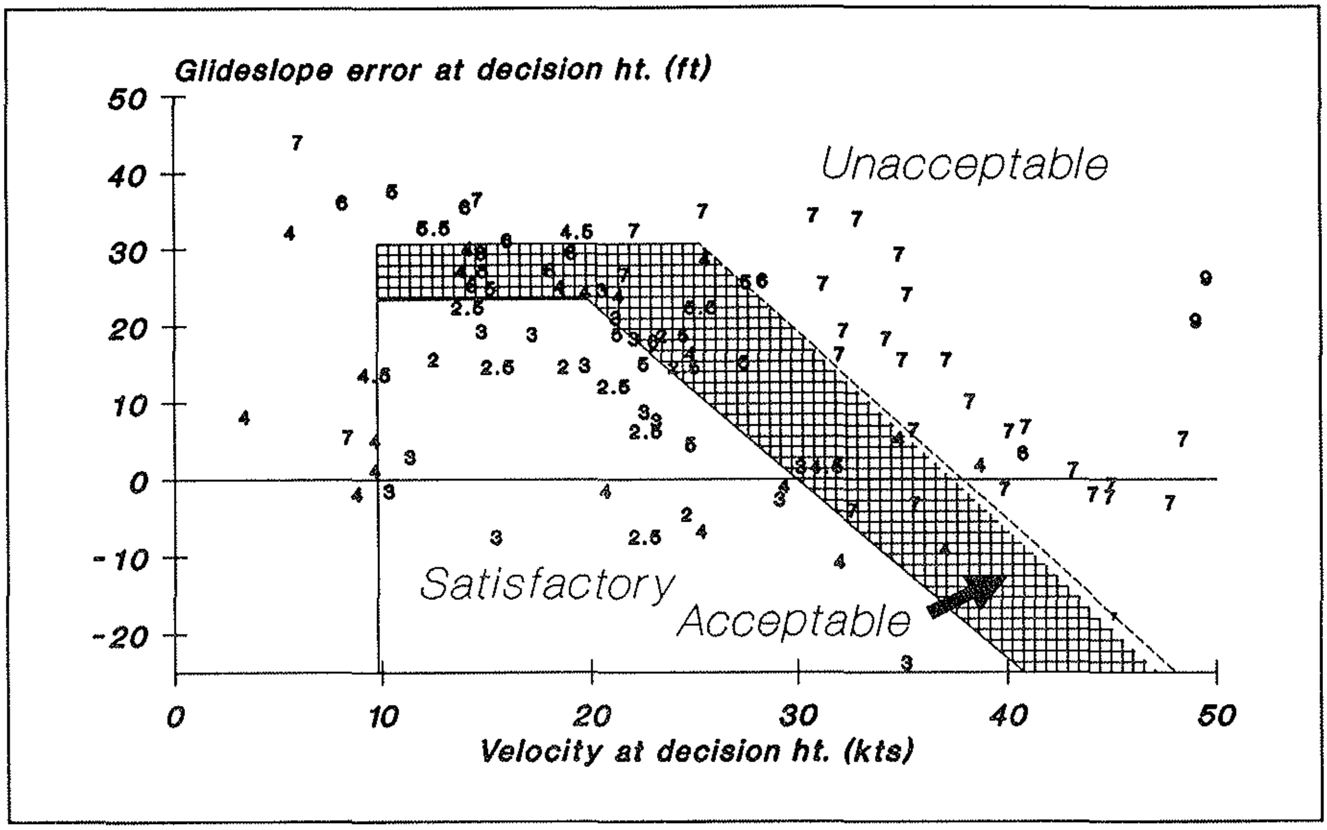

Figure 6 Handling Qualities Ratings for 9 Degree Approaches

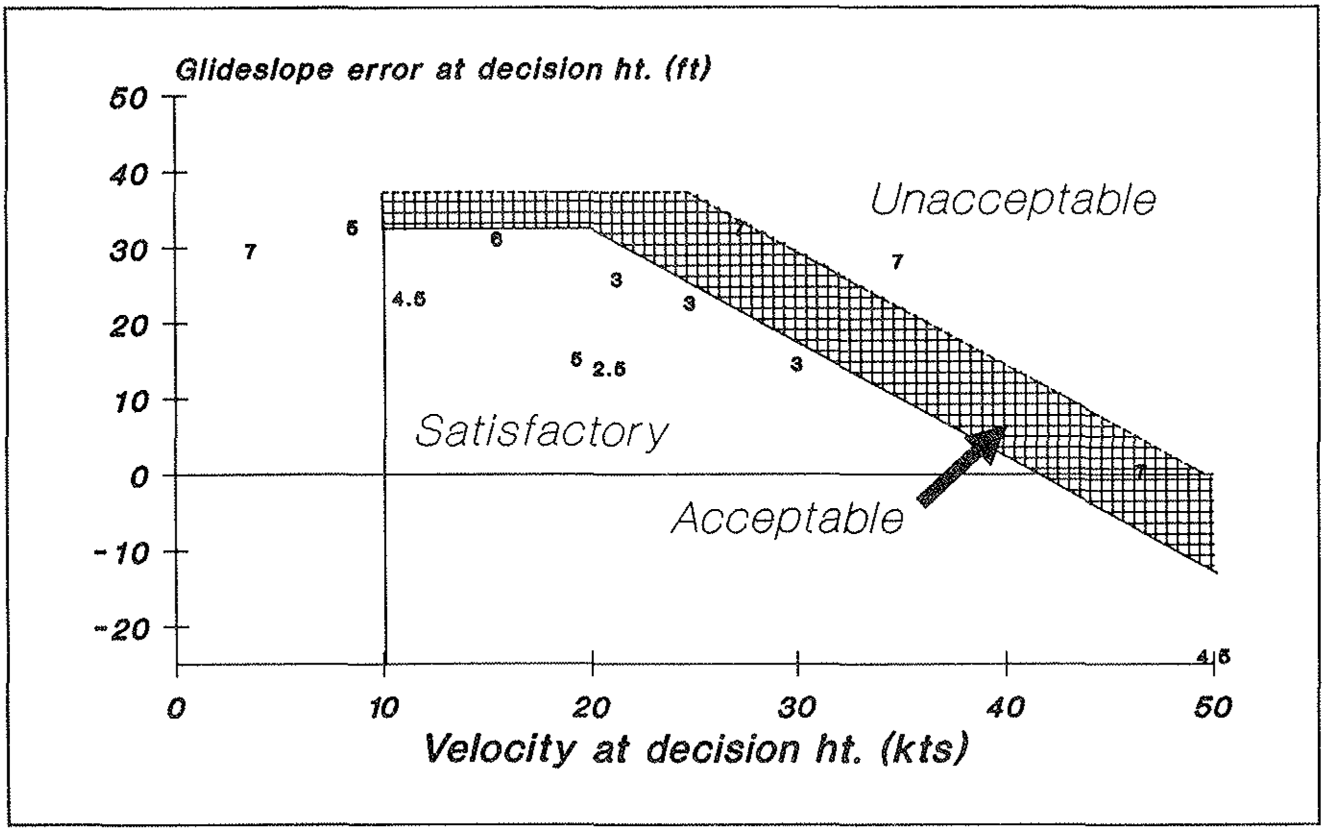

Figure 7 Handling Qualities Ratings for 6 Degree Approaches

No attempt was made to determine the boundary for being low on the glideslope at the decision height since the restricting factors for this case would be visibility and pad markings versus clearway off the approach end of the helipad.

The cases where the approach rating was unacceptable due to being too slow were all accompanied by comments citing aircraft vibration due to the transition to hover flight as the cause of the rating. Considerations of the aircraft vibration level while going through this transition, and of the need to maintain some closure rate to the landing pad, must be made before a minimum closure speed boundary can be drawn. The impact of ambient winds must also be considered in this light. Based on the limited data gathered over the course of this experiment, a 10 knot closure rate minimum was chosen as consistent with a reasonable closure rate on the pad and with the evaluations citing objectionable vibrations for transitions starting at speeds less than this value.

Despite some rather large localizer errors at decision height, lateral offset was not cited as the cause of an unacceptable rating or even the source of any pilot commentary. This result suggests that the lateral tracking performed during the course of the evaluations was inside an acceptable lateral error boundary for the case of heading hold approaches.

All boundaries shown on Figures 6 and 7 must be considered with the following points in mind:

1) All approaches performed in this experiment were concluded with a breakout and hover at the landing point. Such a case does not include the typical mental workload of deciding if a visual acquisition of the pad would be possible and whether a go-around should be initiated.

2) For all approaches evaluated during this experiment, the pilot was able to keep the flight director reasonably centred throughout the approach but upon breakout had reasonably large errors in approach tracking (which were indicated in the raw data display). In many operational scenarios, large tracking errors at breakout would be due to poor flight director tracking and so the pilot would have more cues that the approach was going poorly.

Visibility considerations

Evaluations of the restricted visibility transition to hover, those approaches where the goggles were kept at a low level of fogging throughout the evaluation, were unsuccessful at determining the impact of lower visibility at breakout. For these cases, the evaluation pilots unanimously responded that the visual environment of the approach was totally unrealistic and in exact opposition to the nature of the visual environment of IMC operations. This comment referred to the fact that the goggles tended to obliterate the fine texture close to the aircraft yet leave the horizon virtually unaffected while real IMC obliterates the horizon but leaves very close texture unaffected. The goggles were also annoying in that they obliterated the majority of the cockpit as well as those features outside it. These comments, coupled with the fact that the experimental landing pad environment was an area of low contrast with no lighting, suggest that the utility of handling qualities ratings gathered from these restricted visibility approaches is questionable at best.

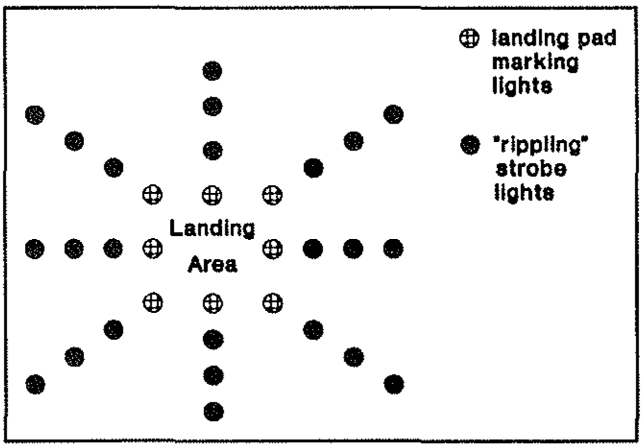

Figure 8 Suggested Helipad Lighting Scheme

Despite the problems mentioned above, certain observations made during these restricted visibility evaluations are worthy of consideration. In most cases the lead-in markings of pad "A" were found to have little use as they were generally below the aircraft and out of sight by the time the aircraft was at the decision height. *(Lead-in markings are useful for the majority of operational environments where the actual breakout to visual conditions would be higher than 50 feet.)* On the other hand, some pilots did remark that markings and lighting which could grab the pilots attention and direct it to the centre of the landing pad would have been useful for the more difficult approach error conditions. These comments would suggest that a lighting system that is at the sides and behind the landing pad, possibly all rippling towards the pad centre, such as depicted in Figure 8, would be of benefit for these operations.

Discussion

An in-depth analysis of the envelopes of acceptable and satisfactory error states at decision height for the 9 degree decelerating approach is currently being conducted. Two concepts which may describe the factors delineating acceptable from unacceptable error states are being considered. The first concept is that the "acceptability" of a given error state at decision height is entirely related to the magnitude of