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Initial Investigation of Head-up Display at B.L.E.U.

by

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THE PILOT'S SAFETY PROBLEM IN CATEGORY II OPERATIONS AND THE POTENTIAL CONTRIBUTION OF HEAD-UP DISPLAY

INITIAL INVESTIGATION OF HEAD-UP DISPLAY AT B.L.E.U.

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J. C. Morrall

SUMMARY

This paper aims to fulfil two main functions; firstly, it highlights what is believed to be the main safety problem in current bad weather landing and secondly, it presents results of initial flight trials with a head-up display which show that this aid has great potential value for Category II operations.

The safety problem is shown to lie in the limitations of the pilot in controlling the aircraft in pitch, using visual guidance. The head-up display is recommended as a solution to this problem as it can provide an efficient means of combining instrument and visual information. In addition, further improvements could be achieved by optimization of cockpit procedures, whether or not a head-up display is adopted.

*Replaces R.A.E. Technical Report No. 66195 - A.R.C. 29660

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CONTENTS

1 INTRODUCTION

The theme of the Symposium is All Weather Operation, with concentration on what is considered to be the critical area of Category II operations, namely, the transition from instrument to visual flight. In this paper therefore two aspects are presented. First, attention is drawn to the shortcomings of the visual control in pitch during the visual phase which is believed to be the main safety problem in bad weather landing using present-day techniques. Second, results from B.L.E.U. work with the head-up display are given and in particular it is shown how the display can assist in overcoming the safety problem.

Early experience, from 1956 onwards, with such devices as a simple aiming bar mounted on the cockpit coaming, (suggested by Mr. Calvert), the projected Zero Reader, and the P.V.D. led B.L.E.U. to feel that a head-up display system containing more comprehensive flight information could play an effective role in all weather operation especially for landings in Category II minima.

The work of Dr. Naish, R.A.E., produced an electronic head-up display containing such information, and which we considered, therefore, should be investigated fully for bad weather approach and landing. This type was installed in first a Varsity and then a Comet aircraft. Trials have been continuing since 1964 and results from the first phase in the Varsity aircraft are those discussed in this paper.

2 VISUAL CONTROL IN PITCH IN LOW VISIBILITIES

The main safety problem in bad weather landing using present-day techniques is considered to be the shortcomings of the visual control in pitch during the final phase of the approach and landing especially in low visibilities. Mr. Calvert of the R.A.E has given this problem intensive study and the argument can be summarised as follows. In making his decision whether to continue with the landing or not after becoming visual the pilot must assess not only his position relative to the ideal flight path, but also his velocities, both cross track and vertical, to determine where the aircraft is going.

Whilst it is reasonable to expect a proficient pilot to be able to assess the aircraft's position and velocity in the horizontal plane by looking at a segment of approach lighting which includes only one cross bar, it is more difficult, if not impossible, to make a similar assessment in the pitch plane from the same picture. Even gross errors may be difficult to detect in the time available after visual contact in operations to the lower decision heights of Category II. It is believed that visual control of the aeroplane in pitch begins to become reliable when the pilot can see as far as the point on the ground to which his approach path is heading. For a glide slope angle of 3° and a slant range of 400 metres this occurs when the pilot's eye height is as low as 70 ft, and even for a slant range of 800 metres the eye height is 140 ft. This means, to achieve high standards of safety in these visual conditions, instrument guidance in pitch is required to heights of around 50 to 100 ft. Figs.1 and 2 demonstrate effectively the type of pitch performance which takes place when the pilot is completing the approach and landing using visual guidance.

The results of Fig.1 were taken by J. Cook at London Airport when the visibility was about 1,200 metres (Category I). The closure with the runway centreline as the approach proceeds and the deterioration in pitch performance at about 3 to 6,000 ft range are quite apparent. The improvement in pitch performance as the aircraft approaches the threshold can also be seen and it is noted that this takes place at the point where the pilot starts to see the runway threshold and beyond at a range of about 3,000 ft.

B.L.E.U. have recently completed a flight trial where different approach lighting patterns were investigated. A slant range of about 400 metres was simulated with fog screens. The pilots who took part in this trial had made many landings in low visibility both real and simulated and were also well educated in the problems of this type of operation. The results given in Fig.2 again show the deterioration in pitch performance when even these experienced pilots assumed manual control using visual guidance. The pitch performance on this occasion does not improve until after threshold, i.e. when at 400 metres slant range the pilot is able to see the aiming point to which he is going. This flight evidence confirms Mr. Calvert's studies and substantiates the need for instrument guidance in pitch to very low heights even although adequate visual guidance for correcting lateral errors may have been available from higher heights.

The requirement for instrument guidance may be implemented by various methods. Immediate solutions applicable to current techniques are as follows. If the approach aid I prefer is being used i.e. automatic approach then this should be retained to low heights and the visual guidance when available used to monitor the automatic performance. Similarly, if the approach is made manually using the flight director, then ideally the aircraft should be flown by the first officer with the captain monitoring the performance on becoming visual. In both cases the captain should, if possible, refrain from taking control to continue the landing visually until at least he can see the threshold or preferably the aiming point. However if, with either of these techniques, a correction of lateral error is required then ideally divided control should be used. This is feasible with automatic approach, but in the case of the flight director the captain will have to take full control with the first officer monitoring his performance on instruments, particularly in pitch.

In the future the head-up display, as described later, allows a pilot to fly the aircraft using instrument guidance in pitch with visual guidance in azimuth and is therefore an ideal solution to overcome the safety problem of the visual phase.

3 BRIEF DESCRIPTION OF THE HEAD-UP DISPLAY IN THE VARSITY

Before going on to present test results, the head-up display in the Varsity will be briefly described. The head-up display components in the Varsity cockpit, i.e. the pilots display unit and reflector, are shown in Fig.3. Fig.4 shows the display as seen by the pilot. The symbols which were used during the Varsity trials are shown in Fig.5 and are as follows:-

(a) Horizon symbols
(b) Aircraft symbol
(c) Track lines director
(d) Cross pointer and director
(e) Bank scale
(f) I.L.S. glide slope scale
(g) I.L.S. localizer or leader cable scale
(h) Radio height
(i) Airspeed error scale
(j) The phase circle.

In brief, the display was a form of director horizon with added information on auxiliary scales.

The majority of the sensors or control laws which were used to produce the above symbols were already in the aircraft as part of the automatic landing and flight system.

4 FLIGHT TEST RESULTS

The results from the trials to date are briefly given in the following sub-sections. These include:-

(a) the instrument approach performance achieved using the display;
(b) the advantages to be obtained from the display during the visual transition;
(c) the contribution to safety during the visual phase and
(d) initial views on the use of the display to assist the pilot to monitor the instrument approach.

4.1 Approach performance

The standard of instrument performance achieved during the trials using the head-up display both for pitch and azimuth is shown in Figs.6 and 7 respectively. The variation with range of the standard deviations of height and lateral error are shown plotted. For comparison auto-coupler performance is also shown. The standard deviation of error is considered to provide a good measure of the standard of performance achieved with given approach and landing system.

Flight director information was flown in both channels with the additional information from I.L.S. localizer and glide slope signal displayed at heights above 400 ft while at heights below this the glide path signal was replaced by radio altimeter indication. Airspeed error was not considered necessary because the automatic throttle was in use. These results pertain to the instrument phase as there was no contact at any time with outside world clues.

Ground theodolite records were taken of 64 approaches, 32 of which were made using the cross wires director and 32 using the track lines director, and down to heights of the order of 100 ft there was no significant difference in the performance between the two systems. Therefore the combined results covering the 64 approaches are shown. The aircraft was flown in conditions of up to 25 knots head wind, 22 knots cross wind and 15 knots tail wind, the majority of the approaches being in winds greater than 10 knots.

The results given in Fig.6 show that the pitch performance achieved by the B.L.E.U. pilots is comparable to that achieved with the autopilot. Further, for Category II operations with a decision height of 100 ft the United Kingdom has defined a pitch performance aim of a standard deviation of 10 ft in glide slope displacement at 100 ft height. It can be seen that even allowing for deterioration due to equipment tolerances and in-service operation, it should be possible to meet a standard acceptable for Category II operations.

The control law used for the azimuth director was heading with "wash out". This should provide a standard better than a heading stabilised and worse than a rate stabilised system. Also the azimuth radio guidance used for these trials was I.L.S. localizer for the initial approach followed by leader cable for the final stage. The azimuth performance achieved with the head-up display is shown, therefore, in Fig.7 where it is compared to heading and rate stabilised I.L.S. localizer and rate stabilised leader cable automatic approach performance. From this it can be seen that, as would be expected, the head-up display performance lies between the two sets of I.L.S. results, and is slightly worse than that with leader cable. The inference is, therefore, that if a rate stabilised or similar control were used then the standard of performance would be satisfactory for Category II operations, i.e. a design aim of a standard deviation of 18 ft in lateral displacement. However it should be noted that to achieve this standard of performance in pitch and azimuth the pilot is fully employed in flying the director.

A further important point to note at this stage is that during these Varsity trials approaches were made using the Smiths' Flight System and the Sperry Zero Reader head-down instruments and again the standard of performance achieved down to heights of the order of 100 ft was similar to that with the head-up display. From this it can be concluded that during a task such as the approach where the pilot is able, due to the stability of the system, to divide his time between pitch and azimuth then the form of director presentation is not too significant and the performance is almost entirely dependent on the quality of the control laws. The same cannot be said for the landing phase, including the flare, but this is outside the scope of this paper.

4.2 <u>The use of head-up display during the transition</u>

The prime advantage put forward for the head-up display is the ease with which it allows the pilot to transfer from instrument to visual flight. As a result of the B.L.E.U. trials the pilots conclusions confirm this view. They considered the transition from using the display to external information was easy and natural. Contact with the external clues was made at the earliest possible time and pilots were able to transfer without abandoning instrument guidance.

The evidence to date from the approaches in which the head-up display was used with fog simulation confirm the ability of the pilot to combine instrument information with external guidance. Although the pilots were not briefed on the method of combining outside world clues with the head-up display instrument information, the natural method of use was to continue to use the display for pitch control until considerably later than they began to use the external world for azimuth guidance. This confirmed the pilot's own realisation that the outside world was deficient for pitch guidance until the threshold or beyond was in use.

4.3 The safety problem

As mentioned previously it is considered that the main safety problem of Category II operations is the poor pitch control by the pilot in low visibilities when using visual guidance. However, when using this display it has been shown that the pilot can confidently combine instrument guidance for pitch control with external visual guidance for azimuth.

Since at the present time modern automatic flight control systems have computed glide slope and glide slope extension information which can provide the pilot with director information in pitch to low heights, i.e. less than 100 ft, this can be presented to the pilot on the head-up display and can be used during the visual phase causing the glide slope errors to be markedly decreased.

The glide slope extension performance obtained during the Varsity trials is shown in Fig.6. This also shows a certain degree of deterioration in performance during the open loop "constant attitude" type of glide slope extension. Nevertheless, by comparing the performance with that from Fig.2, which is done in Fig.8, it can be seen that the head-up display contributes a marked improvement in pitch performance during the height range from 140 ft down to 50 ft, and should therefore contribute significantly to improved safety. Also shown in Fig.8 is the type of result which it is believed should be achieved using more modern control laws than those available in the Varsity. This shows an even more marked improvement over that achieved with visual guidance.

4.4 Monitoring

The results which have already been briefly described were limited to using the head-up display for manual instrument approaches. We have only just started to investigate in detail the role of the head-up display as a monitor for automatic approach and although it is too early to report on this work, it is already clear that the pilot likes to have instrument information in this position. It allows them to monitor the approach performance with such information as displacement from the glide path, airspeed or airspeed error, radio height and aircraft attitude whilst being able to obtain the earliest contact possible with the outside world.

5 DISCUSSION

In the type of civil transport aircraft which will be used for Category II operations an autopilot is likely to be available and there is no doubt in my own mind that automatic approach should be the prime instrument aid. This is for many reasons. Modern automatic flight control systems with the latest control laws can provide accurate consistent approach performance down to the lower heights needed for Category II. They can be designed to have fail-soft characteristics and their reliability and integrity can be established. The use of automatics relieves the pilot cockpit work-load considerably. It frees one pilot from being fully employed in flying the aircraft and allows him to monitor the instrument approach and effect a missed approach if required while the other pilot can concentrate on the critical visual transition and landing. The availability of more monitoring effort must contribute to safety.

Good as this cockpit procedure is it still has the drawback that the instrumental and visual information are separated during the critical period of the visual transition and final approach and landing. When the captain starts to receive visual information he may be tempted to take over manual control too early, that is when he has adequate azimuth guidance but still poor vertical guidance. Alternatively he may allow the instrument approach to continue to a low height to obtain good vertical guidance but accept an azimuth error which he could reduce if he had manual control. The head-up display, however, has the unique feature in the visual phase of allowing the captain to combine the visual and instrument information and to make the optimum use of both.

I believe, therefore, that the head-up display can contribute to safety in Category II operations. System designers should be studying how it can best be integrated into an automatic flight control system or used just as an instrument flight control system while ensuring that the necessary system safety requirements both performance and reliability are met. Certainly for any application the head-up display itself must be designed to be fail obvious.

In designing a system, the flexibility of the head-up display, whereby different displays can readily be generated for different flight modes must not be overlooked. It might turn out to be advantageous, for example, to present the pilot with different displays for monitoring an automatic approach and for performing a manual instrument approach.

Personally I can already see two possible uses for the display: first, because of the super-position of information it can be used to present monitoring information to the pilot during automatic approach. Our pilots already feel happier about conducting low visibility approaches with this facility. Further if the autopilot fails, flight director information can be immediately presented and the display used as a standby channel. Second, in aircraft where a Category II capability is not already available it might be possible economically to retrofit the head-up display together with a computer of the standard needed whereas it might be too expensive to install an autopilot of satisfactory quality especially from the point of view of runaways. This is an engineering problem which would have to be investigated in individual cases.

As stated in the title, this paper reports only initial work at B.L.E.U. Work is continuing to investigate the optimum information needed for the different modes of operation and how it should be displayed. Some flight work has already started in our Varsity, but plans are in hand to extend it to Comet and augment it with simulator programmes, which it is hoped will commence in under six months' time. This combination of simulator and flight trials is expected to provide a powerful and comprehensive method of investigation. The future programme will not only extend the work on approach for Category II described in this paper, but will investigate also the use, in low visibility, of displays to touchdown, for roll-out and for taxying.

6 CONCLUSIONS

This paper has, it is hoped, fulfilled two main functions; first, it has highlighted what is I believe to be the main safety problem in current methods of bad weather landing and, second, presented results from initial flight trials with the head-up display which I believe show that this aid has a great potential value for Category II operations.

The safety problem is shown to lie in the limitation of the pilot to control the aircraft adequately in pitch using visual guidance unless he can see the threshold or beyond. It is proposed that this can be overcome by cockpit procedures which use the most efficient combination of the instrument and visual information in the height band where the pilot is getting adequate visual information for azimuth control but inadequate visual information for pitch control. The head-up display is an ideal intrument for providing this required blend of information.

The conclusions from the aircraft trials made in the Varsity aircraft with an electronic head-up display installed in conjunction with an automatic flight control system are:-

(1) pilots using the head-up display which presents director together with other information necessary for instrument approaches could well achieve the standard of performance necessary for Category II provided good control laws are used.

(2) The head-up display allows easy transfer from instrument to visual flight. It allows the pilot to contact the ground clues at the earliest possible time and to transfer without abandoning the instrument guidance which had been used for monitoring or control.

(3) Pilots are able to fly part display information and part outside world information with ease. This enables the pilot to use the display to overcome the shortcoming of his ability to control accurately in pitch in low visibilities. An immediate solution to this problem is to present the pilot with director information from the flight control system using glide slope and extended glide slope information. This allows the pilot to use the pitch axis of the display to low heights and thus decrease the probability of undershooting the runway. Azimuth control is obtained from the external information.

(4) Information which enables the pilot to monitor the instrument approach can be presented on the display. This allows the pilot, whose prime responsibility is to look for the visual clues and complete the landing manually, to retain knowledge of the instrument situation.

The Varsity trials reported in this paper are only the start of the investigations into the role of the head-up display for all weather operation. Further studies, both simulator and flight, are planned to decide the optimum form and use of the display for Category II operation and to explore its use in very low visibility to touchdown, for roll-out and for taxying.

Finally, I strongly consider that the evidence to date indicates that a head-up display could make a major contribution to all weather operation. Therefore methods of integrating it with automatic flight control systems to use its advantages and provide the optimum overall system should be investigated. As part of these studies the integrity and reliability of the display equipment must be established and due allowance made for it in the total system design.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions to this paper of Superintendent B.L.E.U., B.L.E.U. pilots, and those members of B.L.E.U. who have been involved in the flight trials.

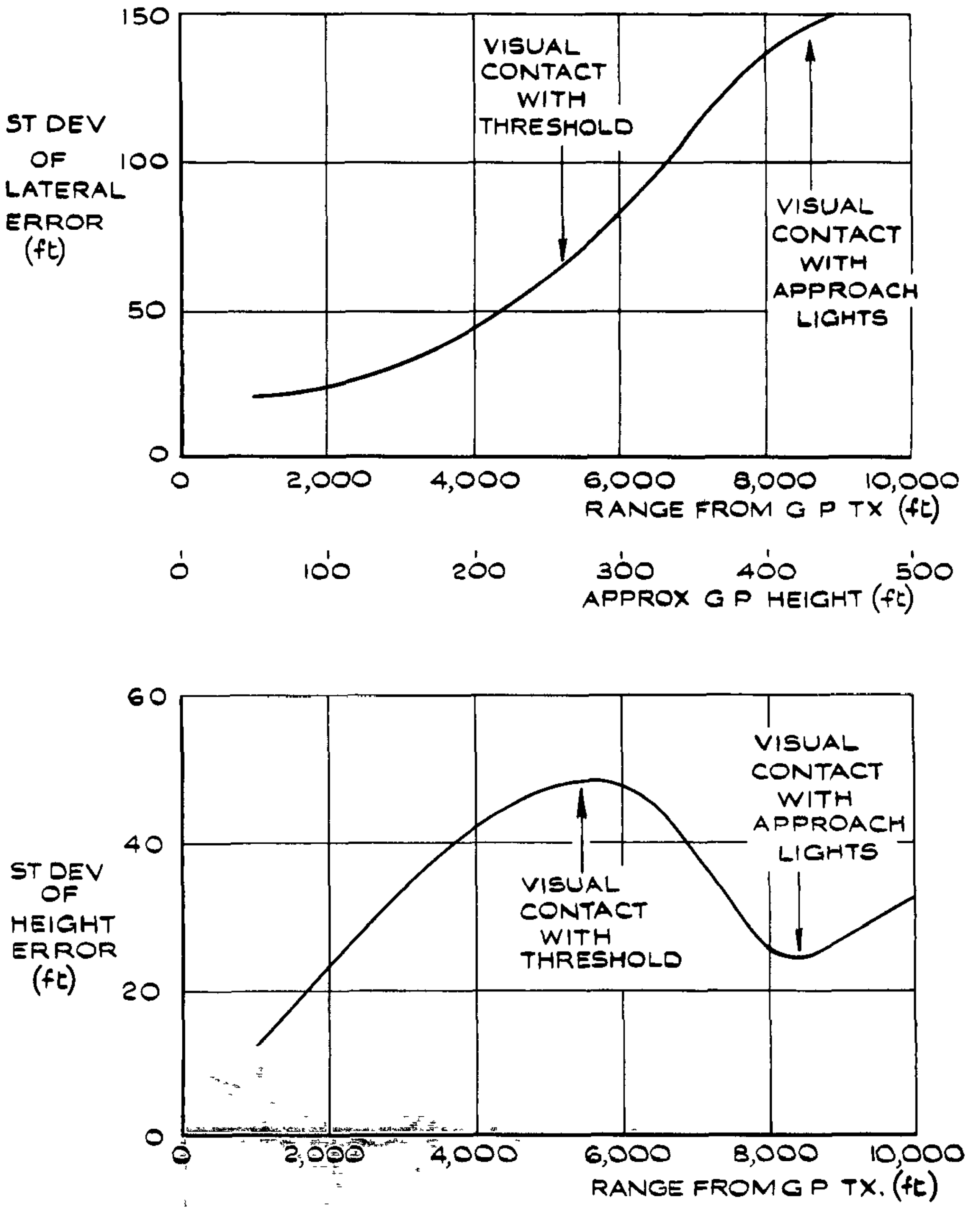

FIG.1 APPROACH PERFORMANCE, LONDON AIRPORT, AVERAGE VISUAL RANGE 1200m

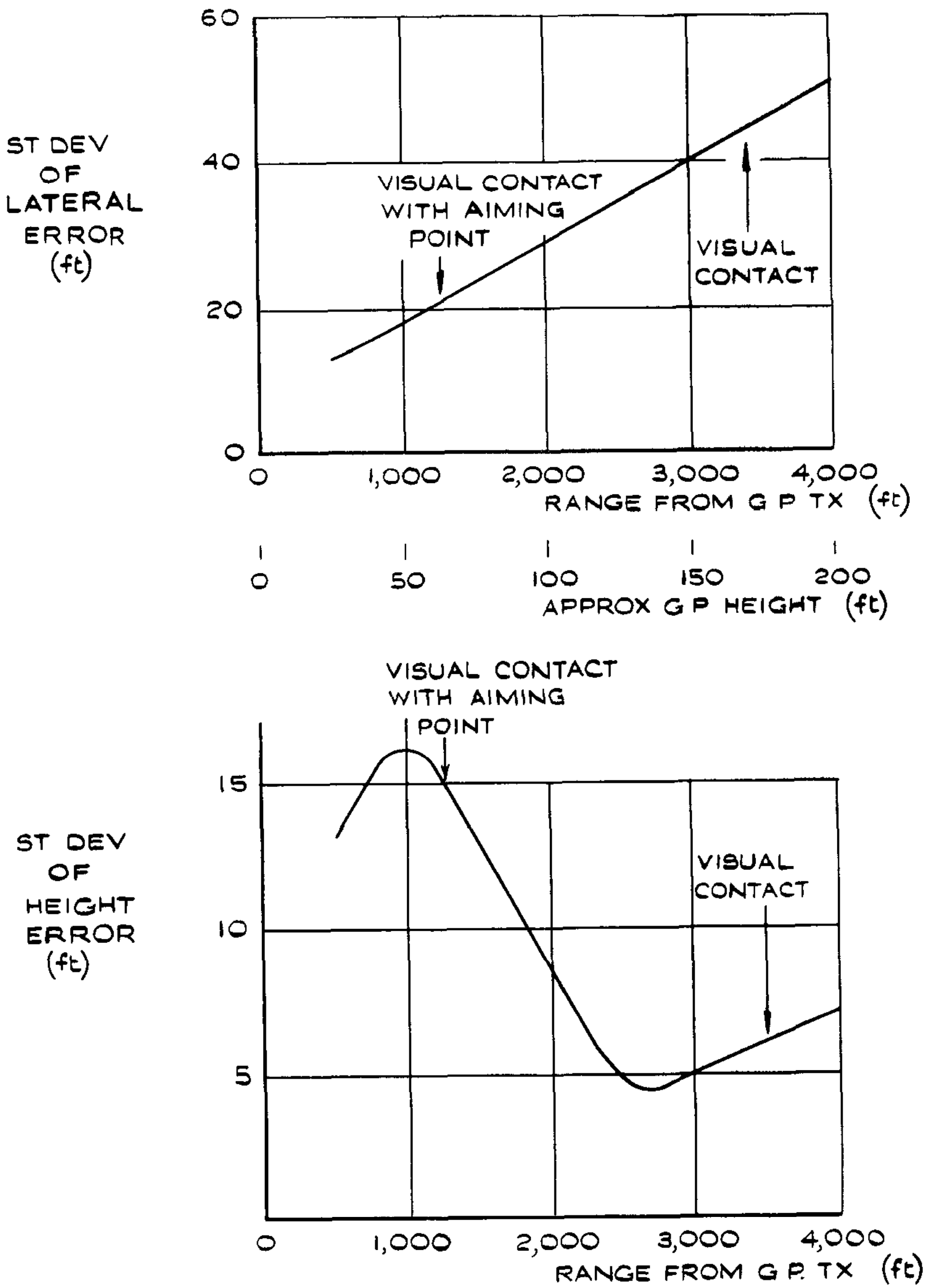

FIG. 2 APPROACH PERFORMANCE, B.L.E.U. TRIALS, SIMULATED VISUAL RANGE 400m

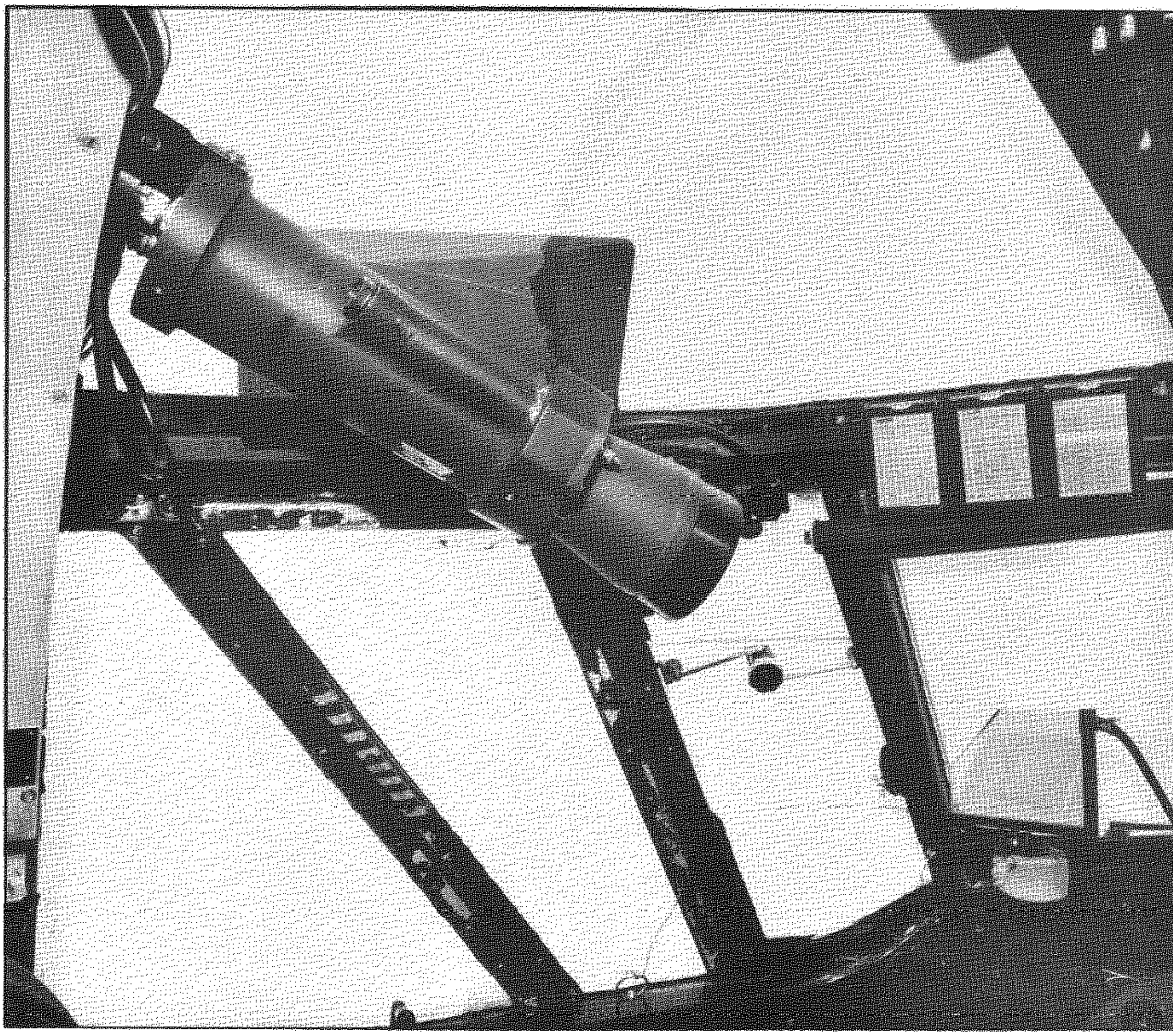

Fig.3. Installation of head - up display in Varsity aircraft

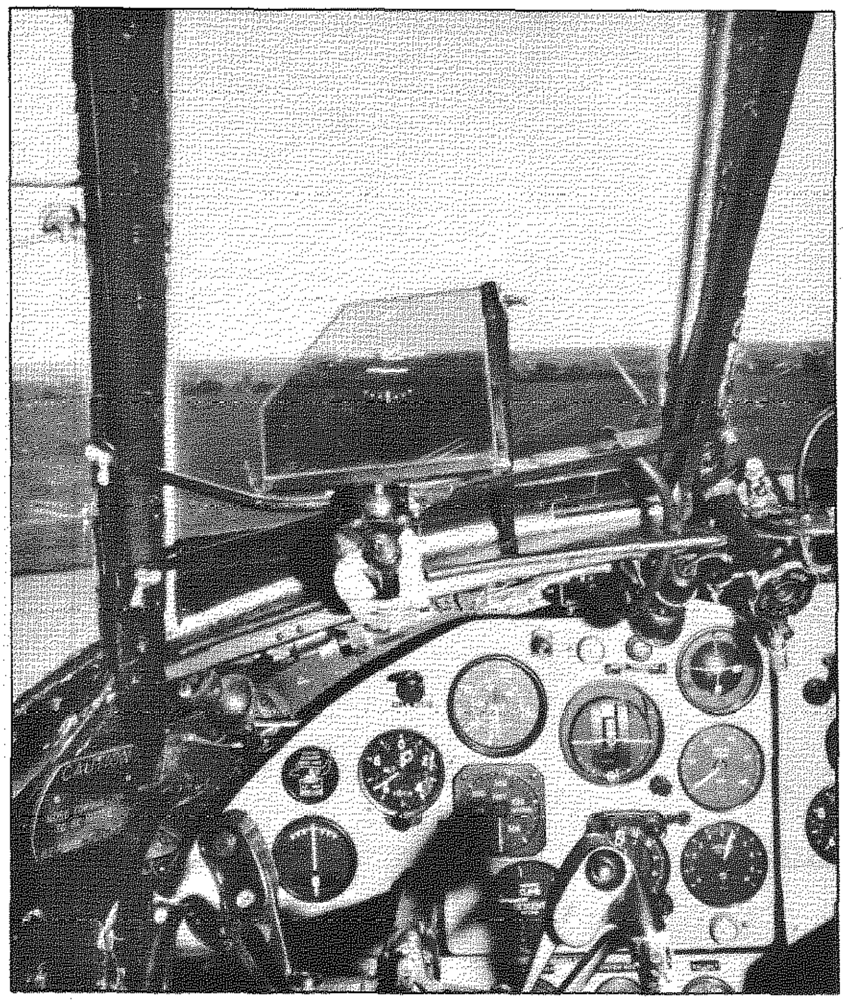

Fig.4. Installation of head - up display in Varsity aircraft showing pilot presentation

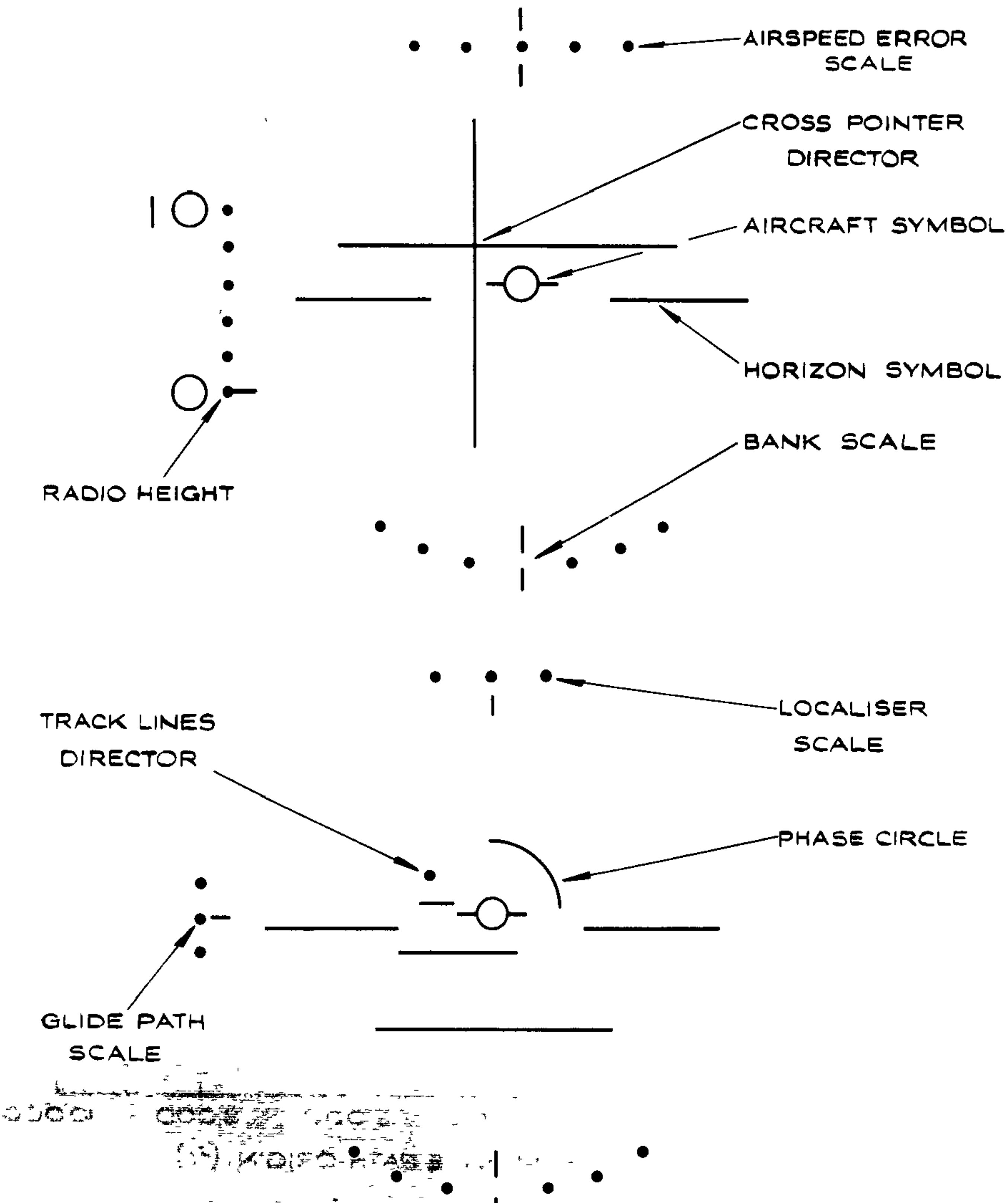

FIG.5 SYMBOLS AVAILABLE ON THE B.L.E.U. HEAD UP DISPLAY

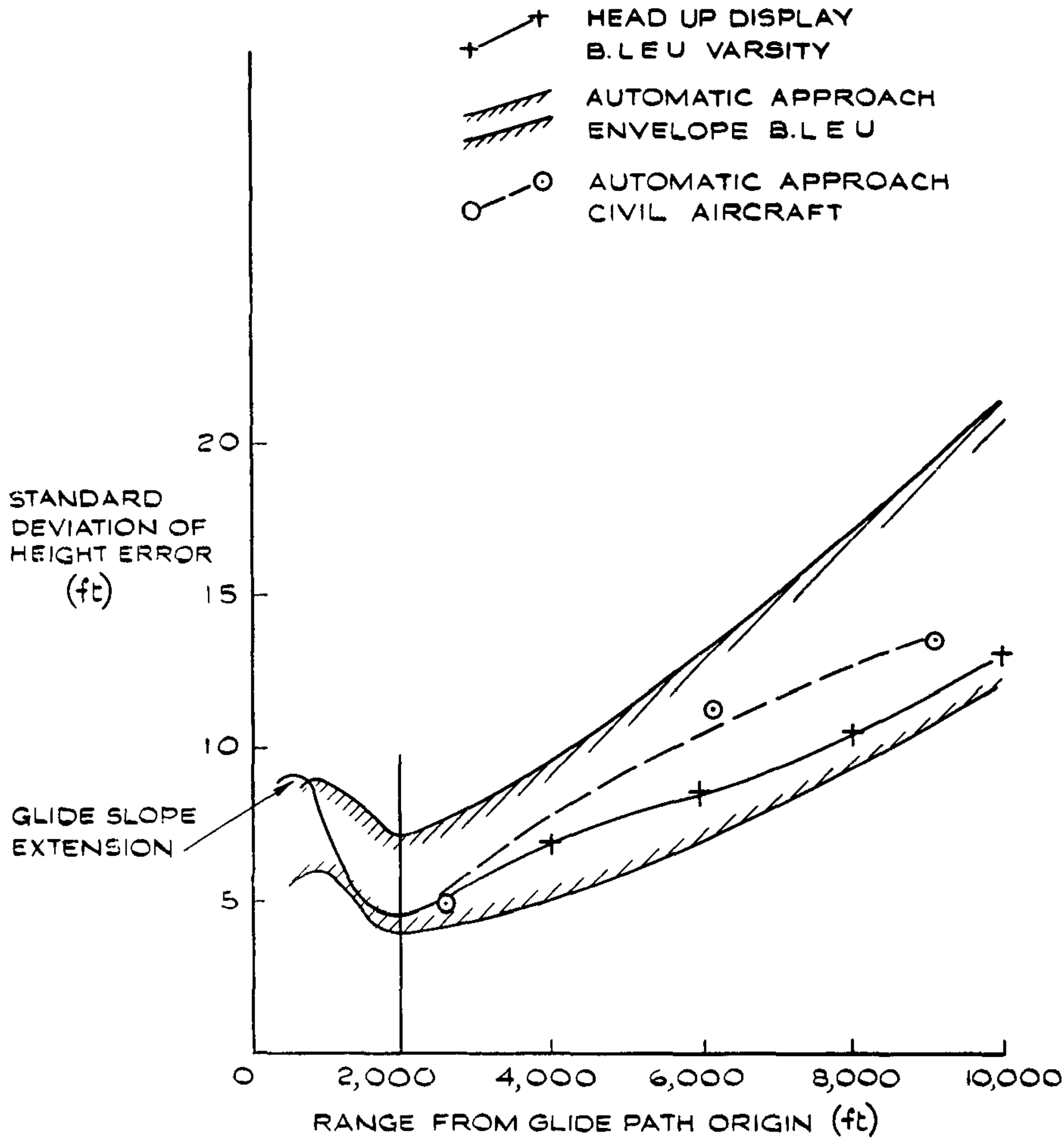

FIG. 6 VARIATION OF STANDARD DEVIATION
OF HEIGHT ERROR WITH RANGE

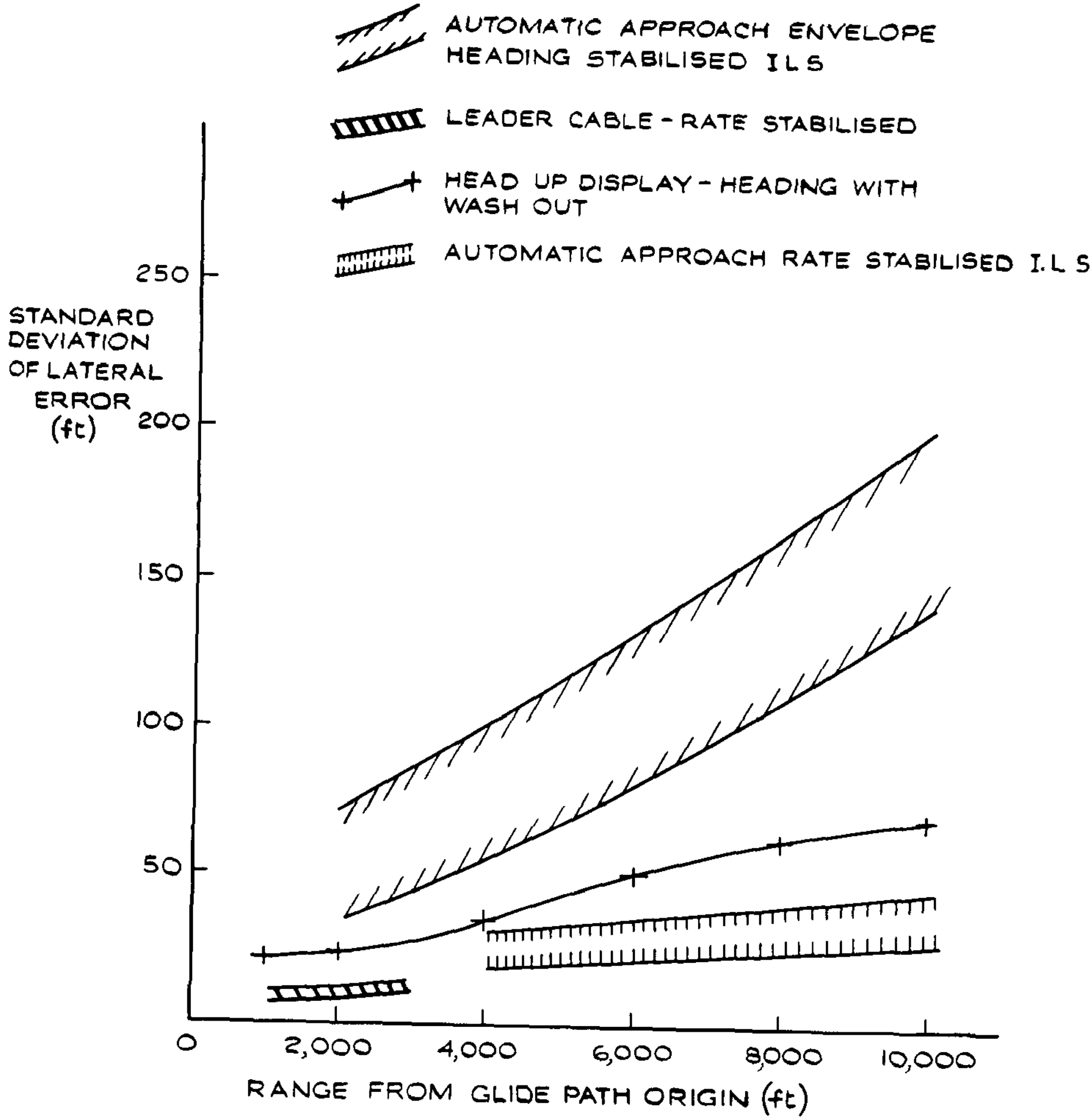

FIG. 7 VARIATION OF STANDARD DEVIATION OF LATERAL ERROR WITH RANGE

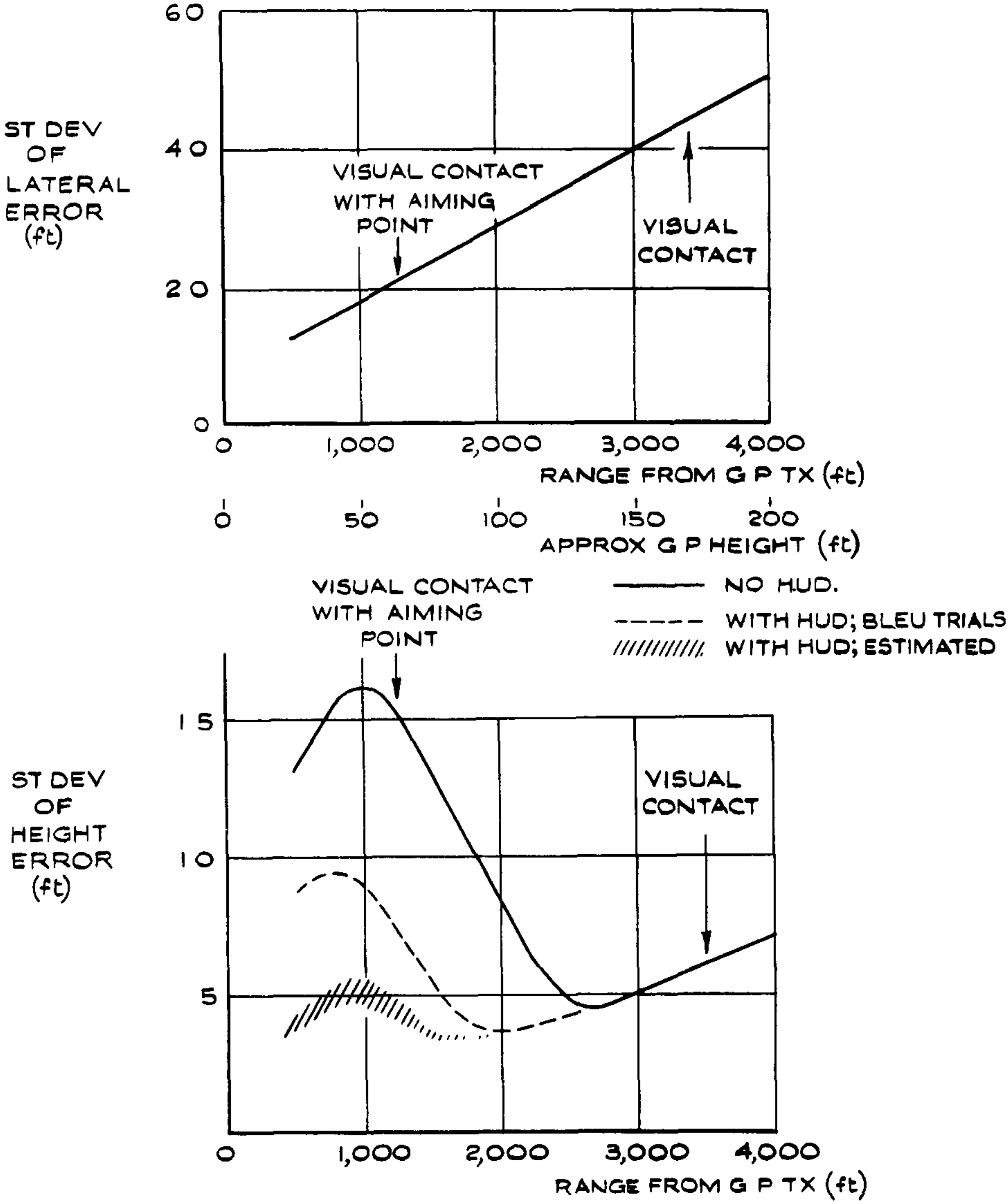

FIG.8 APPROACH PERFORMANCE, B.L.E.U. TRIALS, SIMULATED VISUAL RANGE 400 m

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