NASA TECHNICAL MEMORANDUM NASA TM-75205

EXPERIMENTAL TESTING OF FLIGHT CONTROL HEAD UP DISPLAYS

M. Berjal

(NASA-TM-75205) EXPERIMENTAL TESTING OF FLIGHT CONTROL HEAD UP DISPLAYS (National Aeronautics and Space Administration) 15 p HC A02/MF A01 CSCL 01D N78-17053

Unclas G3/06 05471

Translation of "Expérimentation de Dispositifs de Pilotage Tête Haute," Electronics and Civil Aviation: International Conference, Paris, France, June 26-30, 1972, Reports, Vol. 2, Editions Chiron, Paris, 1972, p. 1033-1046

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 JANUARY 1978

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-75205		

4. Title and Subtitle	5. Report Date
EXPERIMENTAL TESTING OF FLIGHT CONTROL HEAD UP DISPLAYS	January 1978
	6. Performing Organization Code
7. Author(s): M. Berjal	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address: Leo Kanner Associates, Redwood City, California 94063	11. Contract or Grant No.: NASw-2790
	13. Type of Report and Period Covered: Translation
12. Sponsoring Agency Name and Address: National Aeronautics and Space Administration, Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Expérimentation de Dispositifs de Pilotage Tête Haute," Electronics and Civil Aviation: International Conference, Paris, France, June 26-30, 1972, Reports, Vol. 2, Editions Chiron, Paris, 1972, p. 1033-1046 (A73-32508)

16. Abstract Experience and tests with 4 "generations" of head up displays is reported. The CV 191, based on fighter aircraft gunsights and tested in 1964, was replaced by the CV 193, with several improvements, but pilots disliked the large amount of data presented and inability to see data and ground at the same time. The CV 193 V incorporates the Velocity Vector reference mark, eliminates much other data, clusters the rest in a small area of the visual field and is seen together with the outside landscape. Two new head up displays will begin testing soon: the CV 91 presents only Velocity Vector and total angle of descent data, used when runway and horizon are visible; TC 121 displays an outline of the runway and can be used in visual and instrument approaches.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

EXPERIMENTAL TESTING OF FLIGHT CONTROL HEAD UP DISPLAYS

M. Berjal
Air France

Our interest in head up displays goes back to 1964 and, in 1965, we went ahead with the first tests, in a simulator equipped with a CSF 190 head up display, derived from the gunsights installed in fighter aircraft. In this same period, the flight test center (CEV) began a series of tests with the first civilian equipment, the CSF 191. /1033*

I shall begin with these first experiments, because it is as a consequence of and as a complement to this work, with which, moreover, we have largely been associated, that tests were undertaken at Air France. Besides, this head up display can be called the "classical" type, from which those which we have tested on line, the CSF 193 series, are directly descended.

Purpose of Tests

The established purpose was to test whether a head up flight control system was capable of helping in the resolution of the problems raised by lowering of the minimums and by "all weather landing." It had to allow:

Improvement in the precision of manual flight control, or

Monitoring of the approach carried out by an automatic system,

And, in any case, improve the instrument to visual transition of flight control, because, on the one hand, the eye was already accommodated to infinity and, on the other hand, the pilot was already looking in the direction in which the runway should appear.

Installation

The CFS 191 head up flight display was installed in a Caravelle 02 in the copilot position, during installation of the ATT Sud-Lear system. This head up display could also receive guidance, approach and landing information from the ATT set.

---

*Numbers in the margin indicate pagination in the foreign text.

The head up display head has servomechanisms, reticules adjusted to infinity and the following colors: /1034

An orange aircraft model;

White flight director;

Red deviation location or heading indicator;

Green horizon reticule, composed of a horizon line, roll reference marks and a 5° position reference mark (sensitivity 1/2);

Orange speed scale;

In addition, four signal lamps colored green, amber, blue and red can appear, which correspond to difference sequences of action.

We present there, in color and head up, an instrument panel with all its classical flight control instruments.

Control knobs permit the display of a longitudinal position, with or without drift display operating mechanism and regulation of the semi-reflecting mirror.

Results

The representation is well adjusted, particularly the flight director set and the aircraft model.

Despite the number of parameters, utilization of colored reticules, permits good differentiation of them.

The performance obtained is very good.

All the pilots readily passed through the catagory II slots at 100 feet (15 μA in location, 65 μA glide) and, after brief practice, the performance is equivalent to that of a modern automatic pilot using the same calculator.

On the other hand, assistance in the transition did not become clearly evident.

The horizon pitch sensitivity was discussed for a long time. /1035
After initial favorable conclusions of a 1/2 sensitivity following the 1965 tests, it was finally directed towards a 1/1 sensitivity, which now appears as the only possibility, since the entire interest of the head up display is precisely in its capacity of preserving the actual angles and of permitting agreement between the instrument data and the information furnished by observation of the outside world.

Air France Experiments

Following these tests and others, which were carried out at CEV in 1968 and in which Air France participated, it was decided to conduct a series of experiments at the Company.

It began in 1969, on a model derived from the preceding one, the CSF 193. The objectives were the following:

1. To make sure that the good results obtained at CEV, in a Caravelle equipped with ATT Sud-Lear, were not due essentially to the quality of the information source; to also make sure that, with the standard equipment of our Caravelle, of the Z5 calculator in particular, it was possible to satisfy the certification conditions of a category II approach in the manual mode; this installation would have represented about half the cost of installation of the ATT Sud-Lear;

2. To evaluate the ease of use of this equipment under on-line working conditions and to attempt to define the optimum representation; to analyze the operating costs and to determine a distribution of the onboard tasks, with account taken of the fact that installation of only one head up display in the left set was considered a priori.

Installation

This head up display is a clearly improved version of the CSF 191:

The space occupied is reduced;

Installation at the ceiling is done without modifying the instrument panel;

The visual field is improved, which permits normal head movements;

The sensitivity of the artificial horizon is definitely 1/1;

A rate of climb indicator and a roll indicator were added.

After several flights, the required techniques for different settings, in particular, for adjustment of the sensitivity of the flight director, on-line experiments began in December 1969.

In the first phase, only 30 pilots participated in these experiments, each one having received a briefing and carried out an average of 3 approaches during technical adjustment flights. /1036

Results

Three hundred ILS approaches were recorded during regular flights over terrain equipped with good ILS, not necessarily of category II:

The results confirmed those obtained at CEV.

At the 99% confidence level, in 95% of the cases, the deviations were within the following limits:

In location, between -8 μA and + 13 μA (-6.5 m, + 10 m);

In glide, between -43 μA and + 58 μA (-2.1 m, + 3 m), values largely inside the category II slots (± 15 μA in location and ± 65 μA in glide).

Certification of the equipment for category II approaches in the manual mode, moreover, were released by the administration on 15 October 1970.

It also was confirmed that, with a given source of information, a better presentation of the parameters and a greater sensitivity improve guidance precision. Clearer confirmation that the series of recordings of ILS approaches in another Caravelle, using the standard instrument panel (Sperry Horizon HZ4 and the same Z5 calculator) occurred in parallel, and it caused a much greater dispersion.

So much for the figures. But what did the pilots think of it? A number of observations were made, of which here are the principal ones:

1. With the present head up display, such a large number of parameters that it is difficult to grasp them all; in particular, the vertical speed, rate of climb and altitude scales are difficult to read and interpret;

2. A feeling of isolation is experienced, a kind of tunnel effect, which makes the pilot feel no longer integrated with the rest of the crew and is cut off from other information than that supplied by the head up display; this feeling fades and disappears after 5 to 10 approaches;

3. The unaccustomed sensitivity of the information is /1037
a bit bewildering at the beginning and it gives the pilot the impression that he has a clashing flight control; in fact, the recordings show that the actions on the controls remain slight and the comfort of flight control is perfectly normal;

4. The forms of the model and of the flight director, permitting them to be maintained in perfect agreement, are unanimously appreciated; the color display of the reticules is considered necessary to permit good identification of them;

5. The space occupied by the head up display in the cockpit and its position close to the pilot's head causes some inconvenience; the rubber protection appears to be a bit illusory in the case of a large impact; on the other had, it is satisfying to know that the mirror, necessarily close enough to the face to provide an adequate field, is retracted by a smaller impact;

6. Utilization of the position scale as a slope scale, due to its 1/1 sensitivity, has not been of the interest it ought to be, because of the poor quality of the vertical provided by the gyroscopes; in fact, one must not think of measuring an approach slope on the order of 3° to about 1 or 2°...

7. The large number of parameters which occupies the visual field interferes with seeing the runway during landing, with the result that numerous pilots were led to retract the mirror.

In fact, another phenomenon was brought out, and the problems of IMC-VMC transition, which it seemed ought to be solved with the use of any head up display, is not automatic for many. Although by hindsight, the pilot does not see the outside world, because all his attention is required by visual scanning of various parameters presented as though on a classical instrument panel, their interpretation and the flight control actions which flow from it. It is flight control entirely by instruments and outside perception is useless, indeed, it interferes in this flight control loop; besides, the brain eliminates it. When the runway has been visible for a long time by a pilot not at the controls, the pilot using the head up display has to make an effort to see it, as if he needed to accomodate, which has made some say that the information /1038
does not appear to be adjusted to infinity. It is incapable of integrating a simultaneous perception of the outside world and the instrument readings.

If a balance is struck at this stage of the experiments, it can be said that, while the numbers speak in favor of the head up display (incontestably greater flight control precision), the device only finds a moderate welcome by the pilots. On the one hand, it involves too great a number of parameters and, on the other hand, these are simply projected onto the outside world, without being integrated there. Only the properties connected with the great sensitivity permitted are used and, if its installation in old aircraft by "retrofit" is considered, to permit lowering of their minima to category II, it does not seem to give an ideal presentation or to be the optimum solution in future aircraft.

CSF 193 V Head Up Display

These evaluations were assumed to be ended on the Caravelle, at the time Chief Engineer Klopstein of STA tested a flight control technique based on a new piece of data called the "velocity vector." This concerned the "air velocity vector," flight path and aircraft support information at the same time, obtained from the incidence sensor. Moreover, contrary to a well establish idea of the inaccuracy of incidence sensors, the sensors currently installed on aircraft have a fully sufficient accuracy, from 1/5 to 1/10 of a degree. Their correctly filtered signal, corrected by the factor k=local sensor incidence/fuselage incidence, can be used directly.

The air velocity vector, which indicates the direction of aerodynamic flow, thus the air flight path of the aircraft, can only be used together with observation of reference marks connected to the outside environment.

The most appropriate means of presentation is, therefore, a head up visual display. The pilot sees the end of the velocity vector, in the form of a bright reference mark moving over the landscape and indicating the touchdown point of the flight path. Any action on the stick, of a magnitude which modifies the vertical aircraft flight path, causes displacement of the end of this flight path, i.e., the bright reference mark, over the landscape. /1039
It is enough for the pilot, with the stick, to place and hold the end of the velocity vector on the exterior point where he wishes to see his flight path end (on the horizon in horizonal flight, on the approach end of the runway in the approach).

On the other hand, for a given configuration, flight conditions which ensure the same margin of safety with respect to the stalling speed is, whatever the weight of the aircraft and the load factor, characterized by a given angle of attack. For example, aboard a Caravelle in full flight configuration, an approach speed which is 30% greater than the stalling speed corresponds to an angle of attack of 4°2'. Also, if a reference point is marked at this angular value below the model, which itself represents the axis of the fuselage, it is sufficient to maintain the VV opposite this reference mark to be at a good angle of attack, i.e., at a good speed. This steadiness of speed obviously occurs by means of the throttle.

There is a second way of placing a reference mark at a fixed angular distance from the model. This is to shift towards the bottom of the model itself by this amount, the position of the model which indicates the aircraft position actual being of no interest in flight control. This presentation likewise is more elaborate. In fact, if an aircraft, descending at a given slope, characterized by a fixed position of the VV reticule for example, the approach end of the runway, which is held by action on the controls, a continuous decrease in speed is characterized by a more and more nose up position of the aircraft. The model, first below the velocity vector when the speed is too high, will move opposite the VV at a good approach speed and will go above, when the speed becomes too low. Perhaps this also visualizes better the too much nose up attitude of the aircraft (speed too low), when the model itself is the reference mark of the angle of attack.

If it is known that 1/5 of a degree is easily estimated in a head up display and that at the approach speeds, a 1° angle of attack corresponds to about 5 knots, it is seen that its speed can be maintained to within about 1 knot. In fact, the difficulty for the pilot will be, not to obtain this useless performance, but to convince himself that a deviation he believes important is hardly detectable on the airspeed indicator.

As a result of the concluding tests, carried out by some /1040
Air France pilots in the N 262 of the Higher School of Aeronautics, it was decided to modify two CSF 193 head up displays to furnish the Velocity Vector information. The Caravelle was already equipped with one, and another was intended to be installed in a Boeing 707.

Two representations for the angle of attack reference mark were available, and it was possible to change from one to the other in flight, by moving a switch and by turning the mirror at the same time. The VV was represented in this head up display, in the form of a large dashed line operated on rollers.

Advantages of Velocity Vector and Results of this Series of Experiments

The rate of climb indicator scale having become useless, it was removed. Visualization of the flight path is actually more important information and more directly useable than the vertical rate of descent. The speed scale was saved, but a switch permitted the pilot to extinguish it on request. All the pilots very rapidly maintained approach speed by means of the angle of attack, and they decided to extinguish the speed scale. As to the representation of the angle of attack reference mark, the great majority chose the model shifted 4°2' toward the bottom, and that was for two reasons:

The first was that, in an instrument approach, and so, on the flight director, this being associated with the model by definition, all the necessary information for flight control (flight director, model, location and glide deviation and velocity vector) to maintain speed were grouped in the same area; this also avoided a large visual scan, from which there was a reduction in fatigue and greater speed in reading the information;

The second was that this set of information, regrouped around the velocity vector, also was on the end of the path and, thus, on the approach end of the runway; further, due to the VV, which was the prime information, aside from the horizon line, not only by superposition over the landscape, but associated with and connected with the outside world, as it visualized a point of touchdown on it, it also appeared that the pilot at the controls then saw external reference points, the approach end of the runway in this case, much sooner than before. The IMC-VMC transition was found to be considerably easier.

Adoption of the velocity vector brings about another beneficial repercussion. While the preceding head up display was only useable in a IMC approach, with a flight director, over terrain equipped with ILS, this one was now used, although in a still different manner, also in visual approaches. /1041

In such an approach, once placed on a slope believed to be good at first, in the absence of sufficiently precise vertical information, the pilot easily keeps it there, by setting the VV on the approach end of the runway, at least in still air. If there is a headwind, the VV must theoretically be raised by an angle $\delta=\gamma$ [illegible symbol] $V_{wind}/V_{aircraft}$ ($\gamma \simeq 3°$), to maintain a constant ground flight path γ.

In practice, at the start of the approach, it only requires seeing a little further than the chosen touchdown point at the end of the approach. At most, if no correction was made, the flight path described would end at the touchdown point seen, all the same, but it would be slightly curved vertically. If the slope scale is exact (vertical inertia), the pilot can verify at any time that the approach end of the runway is seen at a good slope and possibly apply the necessary correction, by using the VV as a slope director.

All pilots have appreciated the assistance to flight control which this flight path information has contributed in a visual approach, and there is positive agreement on it. All have rapidly adapted to its use, for it is instinctive. Accordingly, it is easier and more accurate to maintain the slope in approaching the runway and, in the final approach, it is possible to see a very exact point of the approach end of the runway. Not only are the risks of too short or too long a landing avoided, but the spread of touchdowns is considerably decreased. Measures taken in a large number of landings made by day and night, by a Mirage III equipped with a small head up display having VV information, has demonstrated astonishing results.

Landing

Moreover, accordingly, the touchdown is more exact than the landing itself, which hitherto depended on the art of flight control, can be executed by a sure and repetitive technique. At a precise time signal (30 feet for the Caravelle), provided by radio-altimeter, which is shown in the CSF 193 by lighting of the blue signal lamp, the pilot raises the VV, so as to see 300, 400 m ahead. The touchdown is full without being hard. For each type of equipment, it is only necessary to find the optimum height at which the flare out has to be started and the amount (distance or angular) by which the VV has to be raised, to obtain a perfect landing, always under the same conditions. It must be noted that the effect of the ground involves a modification of the flow around the aircraft, which explains why the VV must not be raised to the horizontal, but generally to the order of 0.5 to 1° below. /1042

Wind Gradient

The wind gradient, which is expressed by a rapid decrease in the speed of the aircraft with respect to the air, is immediately evident in the head up display, by means of the VV. Without action on the controls, the pilot sees the VV recticule displace toward him in front of the approach end of the runway, which shows well the downward sag of the path, as a result of loss of lift. By immediate and instinctive action on the controls, the pilot replaces the VV on the point of the approach end of the runway which was seen initially. At the same time, he increases power, to restore the angle of incidence, which had increased, to its initial value. These two actions are executed by reflex, without any loss of time.

For all the reasons we have just seen, the addition of the VV was a decisive improvement in the use of the CSF 193 head up display, to the point that the divided opinions at the start of the series of experiments on the first head up display have been brought together in favor of this new installation.

To be sure, the space occupied was not reduced and the front of the head up display is always located very close to the pilot's head. The criticisms on this subject have been much more numerous for the Boeing 707, in which the head up display also was installed. Beyond a doubt, the fact that the time and frequency of use in approach is very low, compared to the time during which it is an inconvenience during long stages must be seen there.

But, despite the inconvenience and limitations of such a head up display, the technical record was favorable, and it decided in favor of its installation aboard the Caravelle and B 707, in view of the reduction of the minima in category II during manual flight control.

Is this to say that such a device has its place in future /1043
instrumentation? Certainly not, as it is presently defined, which only corresponds to a transitory phase.

Moreover, undoubtedly, because this equipment does not seem to be an outcome in this process, the favorable results of the experiments have remained ineffective.

Another line of head up displays is already coming to light. These are head up displays, in which there is no longer either a flight director, or radio deviations or vertical speed or altitude scales, etc...., but a clear, intuitive, symbolic representation.

CV 91 and TC 121

These two head up displays, built by Thomson-CSF, under STA instructions, are an illustration of what is meant by a new generation of displays. Althought their technology is very different, because the first is made up of slaved galvanometers, while the second is made up of a cathode ray tube, their basic principle is identical. Both of them display the air VV and the total angle of descent, sometimes wrongly called the potential angle of descent.

Total Angle of Descent

The total angle of descent, obtained by means of accelerometers oriented along the axis of the VV, indicates accelerations (positive or negative) along this vector.

A total angle of descent equal to the angle of descent, i.e., the two corresponding reticules aligned, indicates a stabilized speed. The "total angle of descent" reticule above that of the VV indicates that the aircraft is accelerated and the inverse, when it is below.

This balance of the thrust and drag forces along the path is thus represented in a very simple manner, and it permits the pilots an easy selection of the necessary thrust to maintain his speed.

On the other hand, for the available thrust, in a given configuration and speed, the total angle of descent directly indicates to the pilot the slope he can take, without losing speed.

Here again, the necessity of accurate vertical information, under penalty of erroneous results, must be noted. In fact, the vertical error does not only affect the angle of descent, but the total angle of descent as well, while the VV data is independent of it.

Moreover, the Nord 262 of the Higher School of Aviation, with which these tests were carried out, has just recently been equipped with an inertial system. Thus, the experiments will be able to be carried out under better conditions. In fact, to take every possible advantage of the head up displays, sensitivity and precision they permit, it is necessary that the vertical information be at least as accurate as that furnished by the incidence sensor, with a precision on the order of 1/10°. /1044

The CV 91 is a simple visualization of the VV and total angle of descent data. Its reduced dimensions permit its installation within the thickness of a louver. A series of experiments in an Air France Boeing 747 should begin during this year.

But, while this head up display is intended to make visual approaches easy and can only be used when the natural horizon and the runway are visible, the TC 121 is designed to permit IMC approaches.

Besides the data of the preceding one, it actually presents an artificial horizon and a runway image produced from the ILS. The trapozoidal pattern of the fictitious runway is superimposed on the actual runway in unlimited visibility, and it undergoes the same deformations as it in the case of misalignment, and it increases in size when the aircraft approaches the ground. At 50 feet, the approach end of the runway disappears, simulating clearance of the approach end and preparing for the flare out signal. The pilot then closes in the horizon VV, by following the angle of descent designator, which, initially preset to the approach angle of descent, is automatically positioned at the optimum flare out value (here, 0.8°).

If external visual references appear at a given moment, the pilot has no difficulty in going through the sighting unit information to these, since they are blended and since the mental process of flight control is the same in using one or the other. There is no longer two forms of flight control (instrument flight control, visual flight control), but a single one in every case and the same flight control loop as the instinctive reflex of visual flight control.

This process holds true in such a manner that, above all, in the last 200 or 300 feet of the approach, the pilot no longer asks himself if the runway towards which he is heading is the actual runway or the fictitious runway. He only makes the small corrections which finally permit him to put the nose wheel on the dashed lines of the axial line (dashed lines of unequal length, which /1045 give the impression of a perspective view). This same axial line permits him to remain aligned during the landing roll, whether during a "touch and go" or a complete landing.

This equipment certainly is not yet operational. It lacks the required redundancy, failure detector circuits, etc., as well as a shape, better adapted to an aircraft cockpit. Above all, it has to permit all weather landings in zero-zero conditions, another source of guidance independent of the ILS. The cathode ray tube now is ready, without modification, to receive any additional information, such as that from a ILM provided by an onboard radar. Tests of an onboard radar interrogating three semipassive beacons which mark off the runway are now underway in Bretigny, and they appear to be very encouraging.

For the moment, a new flight control principle has proved itself. A new head up flight control instrument putting it into practice has shown that blind landings or landings, even with actual visibility less than 50 meters (under GCA control) are easily executed. It appears that it now is opening the way which, while simultaneously satisfying the electronics experts and the pilots, will finally permit realization of a performance that automatic pilots alone have been unable to realize, an all weather landing.

Only this head up flight control device has the performance which permits the pilot to keep responsibility for control of the aircraft to the ground and, at the same time, to satisfy his psychological need to look to the outside, where touch down will occur at the critical moment of the landing. Besides, it gives the decisive advantage of being capable of being used, following the same method of flight control during all approaches and, thus, of providing the pilot the possibility of maintaining indispensable training and the necessary level of confidence to execute zero visibility approaches and landings.

This is exactly the concern American airline pilots had during their 20 July 1970 meeting in San Francisco, when it was written that "unless a poor visibility landing system can be used for routine landings under visible flight rules, no pilot will accumulate the experience and level of confidence sufficient to /1046
utilize it (perhaps once a month or even per year), when there actually is a need for it. It is impossible to acquire and maintain the necessary mastery, by making some blind approaches during periodic training sessions, and no pilot will accept making landings in flight and under good conditions, under artificially reduced visibility, to maintain his level. In addition, however excellent the data display might be, pilots will not be able to keep their eyes fixed on the instrument panel during the last feet of an approach."

An all weather landing requires a certain level of development, simultaneously of the ground equipment and aircraft equipment.

The infrastructure has made progress in numerous areas. A second means of guidance independent of the ILS remains to be determined.

Concerning the onboard equipment, only the automatic pilots, several years ago, had reached an adequate level of performance.

In contrast, instrumentation has been greatly delayed. It has hardly evolved since the first days of aviation, and it no longer allows the pilot, below certain minima, to effectively control the progress of an automatic approach and possibly to resume the controls or to execute it manually.

A new impetus has been given. The necessary effort to succeed rapidly remains to be made.