" All-Weather Helicopter Systems "

by

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A Paper presented to The Helicopter Association of Great Britain in the Library of The Royal Aeronautical Society, 4 Hamilton Place, London, W 1, on Friday, 3rd October, 1958, at 6 p m

Professor J A J BENNETT (*Chairman, Lecture Committee*)
occupying the Chair

The CHAIRMAN, in opening the meeting, said that it was a pleasure to welcome the first lecturer of the 1958/59 season Mr Gerstenberger, who was Chief of Dynamics at the Sikorsky Aircraft Division of the United Aircraft Corporation, Bridgeport and Stratford, Connecticut, would be discussing the equipment necessary for the all-weather operation of helicopters

The Association was grateful to Mr Gerstenberger and to his Company for making available the benefit of their considerable experience in this field, and they were to be congratulated on having successfully evolved very reliable systems equipment, especially in their latest machine, the HSS-1N, of which Mr Gerstenberger would be speaking this evening

MR WALTER GERSTENBERGER

The title of this presentation is a provocative one, for it should arouse the curiosity of both the optimists and the sceptics As the article is developed, however, it will be seen that the position of the optimists becomes by far the stronger one It will be seen that extensive proof is offered of the progress that has been made toward a true all-weather helicopter in the form of actual hardware in an operating helicopter Although all the problems of an all-weather helicopter are not solved, the conclusion will appear inescapable that the major difficulties have been overcome It will appear also, that the helicopter now is not only capable of matching, but will soon surpass the fixed wing aircraft in all-weather capability

The helicopter has certainly matured a great deal faster than its big brother, the aeroplane, but it can be said without belittling this rapid maturity that the helicopter needs a few more elements before the same state of maturity has been reached One might even say that the helicopter in its present state leaves nothing more to be desired than an all-out effort to incorporate presently developed features into production aircraft

The helicopters operating on commercial routes today cannot always be flown under weather conditions when fixed wing aircraft are operating While a helicopter airline can provide more aircraft to accommodate down time for maintenance, regardless of the number of aircraft it has in a flyable condition, it is out of business during the duration when weather minimums along his route preclude flying This affects revenues during the grounding, but also has a marked effect on potential business in the future Therefore, the most urgent need for an all weather system in a helicopter is to increase the utility of the machine to the point where it will be compatible with fixed wing airline transportation and be able to operate under the same minimum conditions with respect to ceiling and visibility, and under the same icing and other atmospheric conditions

Even assuming however, that fixed wing aircraft will be able to operate under more severe minimum conditions as progress is made in navigation facilities and operating techniques, it is probable because of the unique features of a helicopter that the ultimate helicopter will be able to operate under more severe minimums than aeroplanes The mature all-weather helicopter could then operate more competitively with feeder lines in existence now, and even justify extension of these feeder line facilities because of more dependable operation

For military use of helicopters it is even more important to have the continuous use of an important weapon of defence or attack The lack of this weapon during periods which can be recognized by the enemy will enable him to plan in such a manner as to reduce the effectiveness of this weapon, and to require other weapons to be ready to operate instead of the helicopter In the rescue mission, safe all-weather capability will result in more missions accomplished This result is similar to airline operation, except the object is to rescue someone rather than to expedite their arrival at a desired destination

At this point, it may be well to discuss the usage of the work " system " In the true sense of the word, the system includes all the elements that an airline operator, or the elements of an attack, or defence force in the case of a military operator, that are employed It is assumed that the helicopter is part of this system, but other parts include ground elements and personnel to operate them Having been associated with a helicopter manufacturer for an appreciable period, the author will consider the most important element of this system as the " Helicopter System," assuming that ground elements will be represented in part by some piece of equipment on the helicopter

The helicopter must have a reliable power plant to keep it aloft With a single engine, sufficient altitude must be obtained at its take-off point to provide a safe glide path to an emergency landing spot in the event of engine failure With the steep glide angle of the helicopter, operating altitudes of more than 1,000 feet may be necessary over congested areas to provide the above provision It is also desirable to maintain this altitude to minimize noise complaints However, whenever the ceiling is below this required altitude, the helicopter cannot operate under Visual Flight Rules Helicopters with more and quieter power plants will enable the airlines to operate at lower altitudes because the glide angle with one engine not operating will be greatly improved so that the pilot may stay within sight of an emergency landing site with a lower minimum ceiling If sufficient reserve power is provided to insure level cruise flight with one engine not operating (or to insure the ability to climb over en route obstacles), then can the problem of flying with reduced visibility be considered as the next logical step Continuing the argument further, when sufficient reserve power is provided to insure hovering flight with one engine not operating, landings in congested areas during instrument flight conditions may be considered

The gas turbine is a step towards providing this power plant It is quieter, so it will permit lower altitude flights during visual flight conditions, and its weight/horsepower ratio is low which will allow helicopters to enjoy the required reserve power without penalizing the payload carrying ability too severely Although the expense of these capabilities might be questioned they should be analysed in the light of improved safety and especially considering the additional revenue available by round the clock all-weather operation providing more seat miles per year In discussing requirements, it is well to consider alternate requirements if the prime requirements are difficult to meet technically or economically Let us take for an example a helicopter whose power plant is satisfactory for visual flight rules only, and try to substitute equivalent information during limited visibility flight with better instruments or information displays Since the most important consideration seems to be the selection of an emergency landing area after a power failure, some display of the ground by means of a high resolution radar or similar device would have to be tried to see what altitude above the ground the cloud layer would be to permit a safe landing under visual conditions assuming that the radar was good enough and reliable enough over a route familiar to the pilot to make this operation feasible A flying boat hull operating over a route with water below to provide spacious landing areas would reduce the requirements of the radar or similar presentation for a safe landing Water areas are easily defined by radar The calculated risk of landing on a small object is slight, whereas radar should also define a dangerously large object You can readily see that if the operator does not have the ideal helicopter power plant for instrument flight, he can still approach a certifying agency with an alternate proposal in an effort to obtain instrument flight en route with certain ceiling and visibility limitations imposed

The above comments of the desirability of multi-engine helicopters is not meant to imply that the instrument flights that have been made with single engine helicopters have been made with unjustified risks There are innumerable cases where the conditions justify single engine instrument flight, where the loss of engine does not jeopardise the occupants in the helicopter, nor the people and property below I can recall a rescue mission made with an HSS-1 equipped with Automatic Stabilization Equipment, where critically injured people had to be flown back despite the lowering ceiling in a mountainous area I can also recall when our engineering test pilot, Jack Stultz, was faced with the prospect of waiting on the ground with a prototype HSS-1N because of ceilings close to minimum for instrument flight until he filed his first helicopter instrument flight plan with the Civil Aeronautics Authority, and proceeded to take-off and fly until he broke out of the overcast sixty miles away with a noble assist by Jack Keating as co-pilot Los Angeles Airways has permission to fly through an overcast, provided the time interval in the overcast is limited With regard to instrument flight, single-engine military helicopters are pushing the barriers back, and as development proceeds on multi-engine helicopters, the barriers will be pushed further back

All the military services in the United States (and I'm sure, in other countries) are training their helicopter pilots to fly on instruments after equipping their particular helicopters with the available instruments best suited for their particular mission Should the military need arise, the men and machines are being prepared now to minimise the risk of missions that involve some element of chance due to limited visibility In a military mission the requirements of a multi-engine vehicle is not as mandatory as it is in airline operation However, the requirements for a stable vehicle equipped with proper flight monitoring instruments, and backed up by adequate navigation aids are apt to be more stringent Usually stability, if it does not affect manoeuvrability is desirable for any type of mission The kinds of instruments required and their location on the panel are dependent to a degree on the task the helicopter must perform Navigation aids are even more closely tied in with the job A continued generalised discussion of all the possible solutions to all the conceivable problems would bore even the most stout-hearted individual, and besides, would encroach on the perogative of an instrument panel mock-up board Instead, let us consider a specific example, the HSS-1 helicopter and its latest version, the HSS-1N

It is too large to fly without power controls, hence two sets of independent hydraulic controls are provided, one powered by an engine driven pump, the other by a rotor driven pump Direct current electrical power is furnished by engine driven and rotor driven generators Alternating current is supplied by three inverters, so arranged to take full advantage of the redundancy to provide safe flight during emergencies

Automatic stabilization has been in operation for several years now on the HSS-1 helicopter and has proven to be a good engineering solution to the problem of providing the pilot with a vehicle that he can handle easily and without too much dependence upon external visual cues It has a reliability of about one malfunction in 800 flight hours and it is not improbable that this reliability can be at least doubled In the case of the HSS-1, there is little doubt that during the 801st hour the pilot can fly this helicopter on his instruments without the ASE equipment at a speed above 40 knots to a safe destination The ASE was developed by Sikorsky Aircraft Division exclusively for helicopter use and is described in Reference (1), which includes a discussion of its reliability The fundamental concepts are still considered very sound even though some of them were conceived ten years ago Previously, these concepts were employed to unburden the pilot during visual flight conditions, with the problem of instrument flight a consideration for the future The concept should be reviewed for the helicopter of today

Whether you are flying a helicopter or running a business, two of the problems of attaining smooth operation which need to be considered are the philosophy of authority and the saturation of facilities To put it in terms of the helicopter operation, there can be no doubt that the pilot is the prime authority in the direction of his vehicle but he needs help in order that we do not saturate his mental and visual capabilities The block diagram shown in Fig 1 illustrates the various means that may be employed in flying a helicopter It follows that if every piece of information that controls the flight path of that helicopter must go through the pilot, it is inevitable that the pilot will become the bottleneck in this operation unless means are taken to unburden him of some of these tasks The ASE which introduces stabilization signals without taxing the pilot of the details is an example of this concept

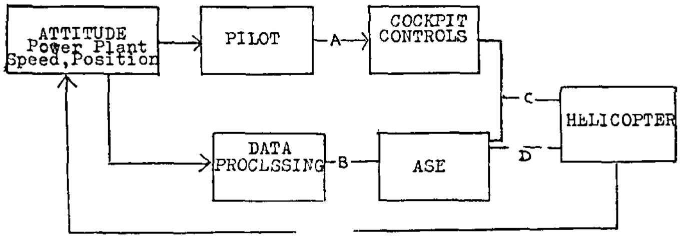


Fig 1

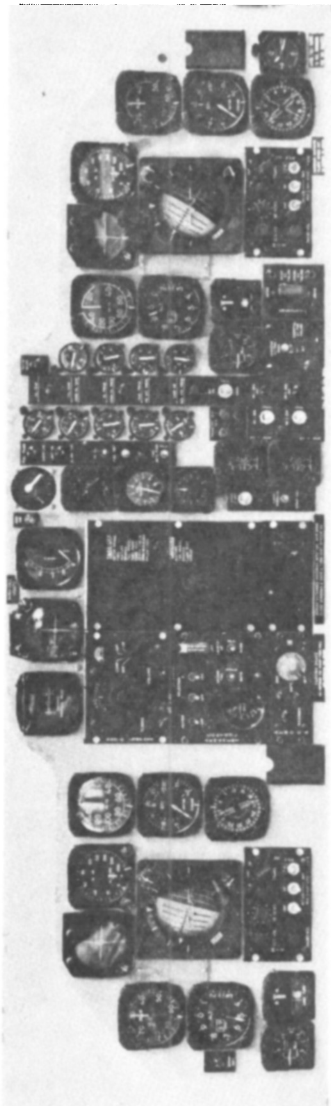
Instead of requiring the pilot to perform all his functions himself, along line A, certain functions can be delegated, along B, to automatic control By limiting the authority of the control to the point where it can still perform its task but leaving the pilot inherently in full authority at all times, especially during emergencies, such as at C, a fail-safe condition exists where 100% reliability is not required for the aid This may be contrasted to a control which cannot be duplicated by the pilot such as at D An example of this is the fuel control of a turbine, where the fuel management is so difficult and so closely related to the structural integrity of the turbine that it appears more feasible to increase the reliability of the automatic control, or rely on several engines, than it is to allow the pilot to control the turbine manually

The incorporation of additional features for improved limited-visibility flying in the HSS-1N preserved this concept of delegation of limited authority used in the HSS-1 but extended it to the Rotor RPM Control in the form of a throttle governor and to the Doppler Hover Mode with the facility of the automatic approach to the hover This vehicle is an Anti-Submarine Warfare helicopter and the facilities added to the HSS-1N provide for " round-the-clock " operation It is an extremely interesting example of a solution to the difficult problem of the approach-to-the-hover and hover over the water with sufficient accuracy so that the sonar transducer may be lowered into the water without damage, all this being accomplished with no dependence on outside visual references The results are the combined efforts of the U S Navy's Bureau of Aeronautics, Naval Air Development Centre, Naval Air Test Centre, the numerous electronic component manufacturers and Sikorsky Aircraft In addition to automatic control equipment, the instrument panel has been redesigned to provide additional information and integrated to provide for a more convenient scan pattern Fig 2 shows a photograph of the new instrument panel

The instrument panel of the U S Navy HSS 1N Helicopter (Sikorsky S 58)

Fig 2

Illustration by arrangement with World Helicopter



1st PILOT S FLIGHT INSTRUMENTS

SERVOS AND GEAR BOX

ENGINE

NAVIGATION

CO PILOT S FLIGHT INSTRUMENTS

To the left of the pilot's panel are all instruments for engine monitoring In operation, when everything is normal, all needle positions are vertical Underneath these are the electrical system control switches which provide selection of alternate electrical power sources

In front of the pilot and co-pilot are the basic flight instruments airspeed, barometric altimeter, rate-of-climb, and turn-and-bank indicator In the centre of this flight group are the essential instruments needed for going into hover from forward flight, all of these entirely new the dual-purpose hover indicator which shows doppler ground speed or cable angle , the improved radar altimeter with an expanded scale to show height above the surface to within two feet , and the remote attitude indicator, with both roll and pitch-trim adjustments Instruments for power monitoring are to the pilot's right, along with the compass

The motor box is still up in back between the pilots, but now is equipped with individual channel disengage switches so that any malfunctioning channel may be disconnected without cutting out ASE completely

The cyclic stick has been shortened for a better view of the instrument panel, and a new besper trim button has been added, which allows the pilot to make small stick-feel corrections without losing his established reference The redesigned grip contains all the familiar switches except the turn button which has been removed

The collective pitch stick has also been changed The hoist switch is now on the collective, and does double duty as an emergency interphone control The engine starter button serves as a disengage switch for the ASE coupler once the engine is started

The ASE panel, as before provides engagement and disengagement for the ASE pitch, roll and yaw , barometric altitude , automatic hovering using the sonar transducer cable as a reference, and hydrostatic altitude It also provides for small heading trims, corrections for fore and aft C G trim and gives a null indication for the servo motor position Controls are also provided for two new functions automatic engine speed, and the seek-and-retain ground-referenced hovering coupler Adjacent is a switch to select between doppler reference and cable reference and another switch to select between hydrostatic altitude or radar altitude

Heretofore when you engaged ASE, you had pitch, roll and yaw stability BAR ALT gave you altitude retention After you lowered the sonar transducer, you switched to ASW cable and ASW ALT for automatic hover over the cable The conventional cyclic stick, without ASE, normally fed through mechanical linkage and a hydraulic servo to the rotor blades ASE input as introduced by an electric servo working through a differential link, to make small, limited authority corrections through the hydraulic servo, to the blades Electric servo input was derived from a comparison of signals from the vertical gyro and the stick-position sensor The resulting signal was then amplified and fed to the electric servo Thus, in normal operation, the attitude of the helicopter was stabilized at an attitude determined by the pilot's stick position The stick-centring spring was used in conjunction with a magnetic clutch When the clutch was engaged, the spring provided stick-feel and a referenced position, if the pilot removed his hand from the stick Disengaging the clutch allowed the pilot to shift his reference to a new position This was characteristic of the pitch or roll control system

Another feature of the HSS-1 was the sonar coupler which operated from a cable-angle sensor The cable-angle sensor induced a signal into the coupler which sent a command signal that was introduced into the ASE to maintain the helicopter in position over the sonar transducer

In the new HSS-1N, important features have been added in the pitch-and-roll channel A doppler ground-speed system has been added and can be selected as the primary sensing for the coupler The automatic control circuits of the coupler will bring the helicopter to a hover from any lateral or longitudinal flight condition However, in order to make it possible for this control to work through the whole flight regime, it is necessary to extend the automatic control authority beyond the limits provided by the servo motor input To do this the magnetic clutch is replaced by another actuator so that when the coupler calls for a signal in excess of what can be provided by the differential input, a signal is sent to this trim control to move the stick slowly in the proper direction which maintains the automatic control within its limited authority When the coupler is not engaged, the trim control can be used by the pilot to make small adjustments to the stick trim

The altitude channel is basically the same as the pitch channel except that the pilot's control is the collective Altitude errors are detected by a barometric sensor, and the coupler is fed either by the hydrostatic depth sensor, or the expanded-scale radar altimeter In order to accomplish the large power changes necessary to go from forward flight to hover, a collective open-loop-and-balance spring is used across the hydraulic servo in conjunction with a collective stick position sensor to automatically adjust the position of the pilot's control

One of the most important additions to the HSS-1N is the doppler ground-speed sensing equipment, which is actually a radar transmitter and receiver As the doppler beams strike the surface, the impulses are reflected back to the receiver-antenna on the helicopter Any motion which exists between the helicopter and the reflecting surface, normal to the radar beam, will cause the received signal to undergo a frequency change Frequency shifts are compared, and longitudinal, lateral and vertical velocities are computed This information is fed to the coupler and the pilot's hovering indicators In the coupler, they are combined with signals from the radar altimeter and other information to bring the helicopter from forward flight to hover at pre-selected altitude

The other new feature of the HSS-1N is the automatic engine speed control A conventional engine-throttle-control on the collective pitch stick is combined, in the differential adding mechanism, with a signal from the output of the collective hydraulic-servo This arrangement permits the mechanical synchronising type of control where increases in power requirements from collective pitch stick motions anticipate the need for throttle increases, thereby preserving the configuration used in manually controlled throttle systems and reducing the work load of an automatic control for engine speed As with the other stabilized primary controls, the command signal for increased RPM or power is introduced in the throttle grip whether manual or automatic control is used Changes in RPM can be effected without the need to disengage the governor itself, and automatic control corrections are achieved without motion of the grip in the pilot's hand

To make an automatic approach to the hover, the area is approached to within 100 feet, where altitude may be maintained with the help of the barometric altitude control When approximately 500 yards downwind of the hover point, and proceeding at about 40 knots, the pilot sets his radar altimeter at say 50′ and engages the hovering coupler which then seeks to null out the forward and lateral drift velocities sensed by the doppler system The circuits are timed to give a uniform reduction in speed and altitude which would simulate the manual approach made by a cautious pilot during a visual approach The pilot, during this blind approach, may monitor this approach with no movement of the controls, or may alter the approach with manual inputs with no disengagement of any of the automatic facilities nor any override forces other than the normal stick trim forces which provide a small force gradient to the controls For example, to come to a closer hover to the water, the radar altimeter knob may be reset slowly, or for a momentary reduction of altitude, the collective pitch stick may be depressed, and then later released to return to the previous altitude Great effort was taken in the design of these automatic controls to make their operation similar to the pilot's manual operations He has to learn the functions of new switches, knobs, and indicators, but he flies the helicopter in the same manner as previously

The HSS-1N illustrates what can be done for a particular mission such as Anti-Submarine Warfare Search with a helicopter It is true that some operators would have little use for a helicopter that could come to a hover over an expanse of water, but it is also true that the techniques and hardware used in this application of instrument flight could be used with slight alterations for other problems

The Automatic Stabilization Equipment has passed all the Civil Aeronautics Authority certification tests, hence it may be installed and used on regular airline service There are no restrictions to its use It may be turned on while on the ground throughout ground and flight operations Modifications of the sonar coupler have been made to provide a tether device, or guide line, which permits a man on the ground to control the aircraft This proved useful during night flights, or over a dusty area when visibility made it difficult or impossible for the pilot to control the helicopter with sufficient precision to hook on to and pick up an external cargo With the same basic coupler, stabilized flight during towing is being maintained The application of this equipment towards a drone helicopter is being tested with the simple addition of a standard radio link used for fixed wing aircraft

When commercial multi-engine turbine helicopters are available in the near future, the necessary automation in the cockpit to assist the pilot will be available as well Government agencies and industries are proceeding with developments of suitable and compatible navigation systems which will accelerate the evolution of an All Weather System Development of improved de-icing equipment is proceeding on current models, paralleled by the incorporation of these de-icers in the original design of the rotor blades in the immediate future When the All Weather System becomes a reality, by virtue of the integration of all the essential elements, there will exist even a greater demand for improved systems with lower cost, greater reliability and less weight The ultimate result must be the satisfaction of these demands to the point where feasibility is no longer a question, merely the degree of perfection as dictated by the law of diminishing returns

REFERENCES

1 Gerstenberger, Walter, "The HSS Automatic Stabilization Equipment" ONR Symposium Report ACR-11, 20—21 October, 1955

2 Gerstenberger, Walter, and Carter, Edward S, "Closing the Loop on the Automatic Stabilization Equipment," American Helicopter Society Thirteenth Annual National Forum, May 8—11, 1957

Discussion

The **Chairman** thanked Mr Gerstenberger for his most instructive lecture and for showing his wonderful films

Mr D L Hollis Williams (*Westland Aircraft Limited*) (*Member*), said that it gave him the greatest possible pleasure to open the discussion, for it was not so many days ago that he had been with Mr Gerstenberger and his team at their Stratford plant in Connecticut, when some of these same problems had been discussed

Mr HOLLIS WILLIAMS proposed not to ask questions, but merely to illustrate and underline one or two things which had already been said The work which had been done by the Sikorsky Dynamics team was really a major break-through There had already been helicopters with automatic pilots, but this was the first time that a complete system had been worked out and it had really put the helicopter in business as an anti-submarine weapon It meant that fleets and merchant ships could now

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