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Case for Aircraft with Outboard Horizontal Stabilizers

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A description is given of what is believed to be an innovative aircraft configuration in which the horizontal stabilizing surfaces are mounted outboard, and downwind, of the tips of the mainplane. It was shown theoretically that the pitch-control effectiveness of such tail surfaces is, due to their location in the mainplane-generated upwash, greater than that of a corresponding conventional horizontal stabilizer subjected to the mainplane downwash. Wind-tunnel and flow visualization tests were carried out that showed that the divided horizontal stabilizer was also usable as an effective lifting surface to augment the lift of the mainplane. It was found experimentally that the lift:drag ratio of the new configuration can be up to about 30% greater than that of an otherwise comparable conventional configuration. The results of flight tests are reported of large, powered, radio-controlled model aircraft featuring the new configuration. These did not reveal any significant problems with flying qualities. A simplified analysis of structural loading showed that provided the design parameters are chosen correctly, wing bending and torsional loads are fairly comparable with those of conventional aircraft.

Nomenclature

A = aspect ratio
b = wingspan
C = positive constant
C_L = lift coefficient
C_m = pitching moment, + nose up
D = drag of complete aircraft
L = lift of complete aircraft
Re = Reynolds number, wing-chord based
U = flight velocity
w = downwash velocity, + downwards
Y = $(2y)/b$
y = displacement from center of wing, Fig. 2
α = mainplane incidence angle
ε = downwash angle, + downwards

Subscript
W = wing

Introduction

FIGURE 1 shows, diagrammatically, the configuration of a radio-controlled flying model aircraft featuring outboard horizontal stabilizers. The objective of what is believed to be the innovative outboard-horizontal-stabilizer (OHS) configuration is to place the horizontal tail surfaces in the upwash generated by the flow about the mainplane. It is, as a consequence, then feasible to employ the horizontal tail surfaces as lift generators since the lift vectors of the tail surfaces are, due to the wing upwash, inclined forward. This helps to offset the induced drag of the low aspect ratio horizontal stabilizer, rendering it a relatively efficient lifting surface. Although the horizontal stabilizer is, by virtue of the arrangement depicted in Fig. 1, divided into two widely separated halves, the vertical stabilizers serve as end plates tending to suppress a tip vortex originating from the inboard end of each half of the horizontal stabilizer. Such vortices would, in any case, be counter-rotational to those formed at the tips of the mainplane.

The span of each half of the horizontal stabilizer of an OHS configuration is limited by the aerodynamic need to locate it within a zone of significant upwash velocity in order to benefit from the resultant forward inclination of the tail-surface lift vector as a means of offsetting drag. A similar offsetting of drag can be achieved using a conventional tail, immersed in a downwash, when generating negative lift. However, this results in the mainplane lift having to exceed the gross weight of the aircraft. The maximum aspect-ratio of the horizontal stabilizer is governed by the desirability of having a less steep lift-curve slope than that of the mainplane to ensure that stalling of the mainplane occurs prior to that of the tail surfaces. It can, by this means, be guaranteed that, at stall, the mainplane is utilized as a load carrier to the fullest extent possible, and also, that stall is associated with a nose-down pitching moment rather than a nose-up pitching moment that could occur if the tail stalled before the mainplane.

It can be seen, therefore, that an OHS configuration provides the advantage, normally ascribed to a canard arrangement, of allowing the horizontal stabilizer to contribute significantly to the lift of the aircraft resulting, relative to a conventional configuration with a nonlifting tail surface, in a smaller mainplane for a prescribed total lift. Relative to a canard configuration, an OHS arrangement ensures full utilization of the maximum lift of the mainplane at the stall condition. This is not usually the case for a canard due to a need

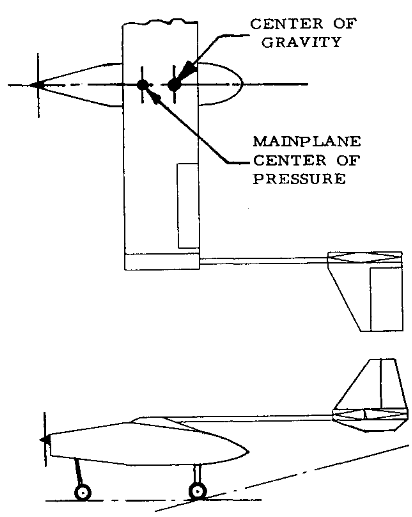

Fig. 1 Configuration of an OHS type model aircraft (diagrammatic).

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for the forward-mounted horizontal stabilizer to stall prior to stall of the aft-mounted mainplane.

So far as the author is aware there are only three prior references to OHS configurations.[1-3] However, about 50 yr ago, the Chance Vought company produced and flew in the U.S., an ultralow aspect ratio experimental aircraft, the V-173, equipped with horizontal surfaces projecting outboard of the wing trailing edge. The prime purpose of the work reported here was to undertake initial wind-tunnel, flow visualization, and flight tests, and also load analyses of OHS configurations of the type illustrated in Fig. 1.

Outline of Theory

An aircraft employing an OHS configuration differs aerodynamically in essentially three major ways from a conventional arrangement. The factors requiring particular attention are 1) the flowfield affecting the horizontal tail-surfaces and the magnitude of upwash that can be expected, 2) the influence on pitch stability of the OHS arrangement compared with the stability in pitch of a conventional aircraft, and 3) the roll control of an OHS configuration. The first two topics have been dealt with previously,[2] and hence, will only be reviewed briefly.

Upwash Velocity

It is well known that the flowfield far downstream of a lifting wing can be modeled as a pair of counter-rotating, parallel, trailing, vortices. For a wing that can be approximated as elliptically loaded, the axes of these vortices are separated, in the horizontal direction, by a distance of $(\pi/4)b$. The two vortices represent the fully rolled-up form of the wing trailing vortex sheet.[4] Figure 2 is a graphical presentation of such a flowfield.

An approximate formulation[5] implies that, typically, vortex roll-up is complete at a distance of about $4b$ downwind. In the vicinity of a wing, Glauert[4] has shown that the upwash velocity distribution outboard of the wingtip was very similar to that depicted in Fig. 2. This result serves as a justification for assuming that the upwash profile depicted in Fig. 2 can be applied at downstream stations close to the wing at the outboard horizontal tail surfaces. The velocity distribution in the upwash flow shown in Fig. 2 suggests the desirability of employing tapered horizontal stabilizers, as illustrated in Fig. 1, in order to maximize the benefit of the greater upwash velocity occurring at the inboard ends of these surfaces. If a horizontal stabilizer semispan is employed of about 40% of the mainplane semispan (a value typical of many conventional aircraft), then the conservatively estimated spanwised-average upwash angle is 18.3 deg (C_{LW}/A_W).

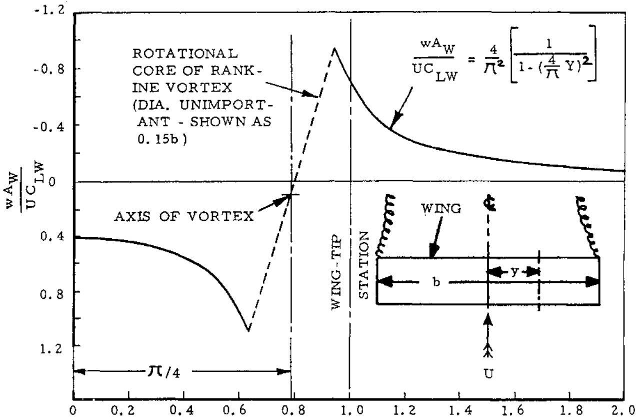

Fig. 2 Flow field far downstream of an elliptically loaded wing.

Pitch Stability

For conventional aircraft configurations it has been shown that pitch stability is generally due solely, in the absence of an ultralow c.g. (i.e., pendulum effect) or significant wing sweep, to the action of the horizontal stabilizer. Since a nose-up pitching moment is defined to be positive, it is essential that the contribution of the tail to the pitching moment be negative if a nose-up pitch occurs, and conversely, must be positive if the perturbation leads to the aircraft nose dropping. It has been shown that for a prescribed flight speed, aircraft geometry and tail efficiency, and where C is a positive constant[6]

$$\frac{dC_m}{d\alpha} = -C\left(1 - \frac{d\varepsilon}{d\alpha}\right) \tag{1}$$

For a conventional configuration $d\varepsilon/d\alpha$ is positive, and typically, even with a raised tailplane, $0.2 \leq d\varepsilon/d\alpha \leq 0.3$. For an OHS configuration $d\varepsilon/d\alpha$ is negative, and for a tail semispan equal to 40% of the wing semispan $d\varepsilon/d\alpha$ has a modulus of about half that for a typical conventional aircraft. This implies, from re-evaluation of Eq. (1), that the modulus of $dC_m/d\alpha$ is increased by about 50% for an OHS arrangement, and hence, from a pitch control viewpoint, such tail surfaces are much more effective than an otherwise comparable conventionally located horizontal stabilizer.

Roll Stability

It is inherently possible to provide an OHS configuration with roll-control by various means. For example, provided the mainplane was of very great torsional stiffness, roll control could, conceivably, be obtained by differential operation of the elevators.[1,2] An OHS aircraft could be provided with conventional wing-mounted ailerons operating in concert with differential operation of the elevators or as the sole means of roll control. When the latter concept is adopted, a concern is the measure of control authority achievable.

Regarding an aileron as a variable camber device, lowering an aileron results in an increase of upwash at the adjacent wingtip. The corresponding increase of upwash angle is typically (i.e., for $A_W \simeq 6$) sufficient to provide a percentage increase in the lift coefficient of the horizontal stabilizer downwind of that wingtip of about half the percentage increase of the local lift coefficient of the main wing. The converse is true on the opposite side of the aircraft. It can, therefore, be seen that there is an automatic coupling of the action of the main wing ailerons with a sympathetic modulation of lift generated by the horizontal outboard stabilizers. This suggests that while aileron surfaces on the main wing only cannot be located to provide the maximum possible roll-control authority, adequate roll-control should be achievable.

Wind-Tunnel Tests

Wind-tunnel tests were carried out to compare, experimentally, the performances of comparable OHS and conventional aircraft configurations. The tests were restricted to relatively low Reynolds numbers, in the region of 6×10^4 based on the mainplane chord, due to the dimensions, and flow speed, of the available open-jet wind tunnel that had a jet width of 1.372 m (54 in.) and a jet depth of 0.762 m (30 in.). The span, over the tips of the horizontal stabilizer, of the OHS configuration was 0.795 m (31.3 in.). The aspect ratio of the mainplane was 6.19, including the booms supporting each half of the horizontal stabilizer, and was 5.92 for the wing alone with the booms removed. The planform area of both halves of the horizontal stabilizer was 40% of the mainplane planform area. The span of each half of the horizontal stabilizer was 40% of the wing semispan. The corresponding conventional configuration employed the same mainplane and horizontal stabilizer surfaces as the OHS model. This commonality ensured that any differences in test results between the two configurations would not be a consequence of manufacturing errors in the fabrication of either the mainplane, which was of NACA 0018 section, or the horizontal stabilizers that had a thickness/chord ratio of approximately 12%. Figure 3 is a photograph of the OHS version of the wind-tunnel model, and Fig. 4 shows the corresponding conventional version. Figure 5 is a reproduction of part of the fabricational drawing, from which the model components were constructed, showing more details of the models than can be deduced from Figs. 3 and 4.

The test data recorded included, in addition to geometric settings of the model such as wing and horizontal stabilizer incidence angles, the model lift and drag and the flow-speed of the tests. For each test the model was mounted inverted in the wind tunnel, on a lift and drag balance, being supported by a hinge-pin from one of the holes, apparent in Fig. 5, in the fuselage component. The hole selected for a test was that located vertically above, in the inverted model, the desired location of the c.g. The model was balanced in the fore-and-aft direction by sliding forwards or rearwards; the metal rod, apparent in Figs. 3–5, attached to the fuselage component. A pointer moving over a scale revealed any deviation from the horizontal setting during the operation of the wind tunnel.

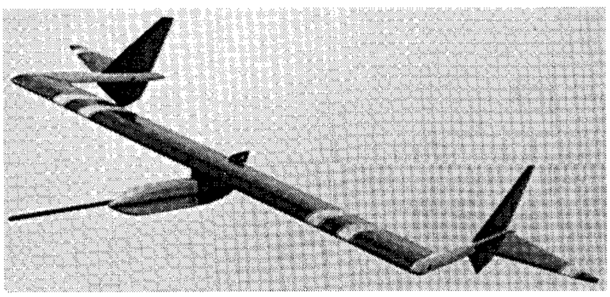

Fig. 3 Photograph of the OHS version of the wind-tunnel model aircraft.

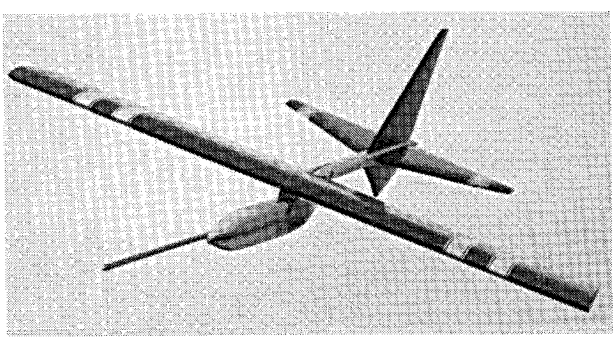

Fig. 4 Photograph of the conventional version of the wind-tunnel model aircraft.

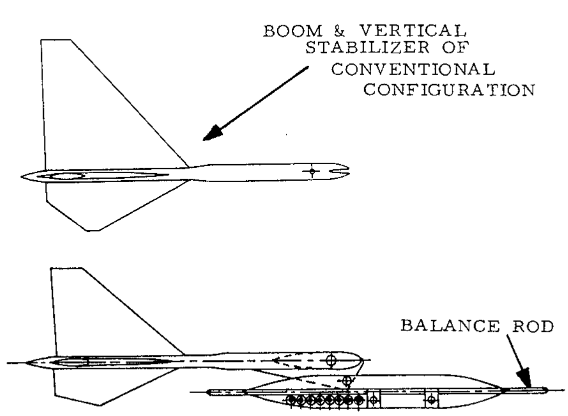

Fig. 5 Diagram, to scale, of the interchangeable wind-tunnel models of Figs. 3 and 4.

A summary of the results obtained from the wind-tunnel tests are presented in the form of lift/drag (L/D) curves vs wing angle of incidence α for the OHS configuration in Fig. 6 and for the corresponding conventional arrangement in Fig. 7. Figure 8 compares two curves, the upper one for the OHS configuration with the c.g. located at 65% of the mainplane chord aft of the mainplane leading edge, and the lower one for the conventional configuration with the c.g. at 23% of the mainplane chord aft of the leading edge. Both these c.g. positions were in the middle of the range explored for each case. As can be seen very clearly from Fig. 8 the maximum L/D of the OHS configuration was approximately 33% greater than that of the conventional version of the model. The drag forces were approximately equal for both versions of the wind-tunnel model, but the lift was significantly greater for the OHS version. The difference between the L/D ratios of the two versions of the model is greater than would be expected if the comparison had been made at a much higher Reynolds

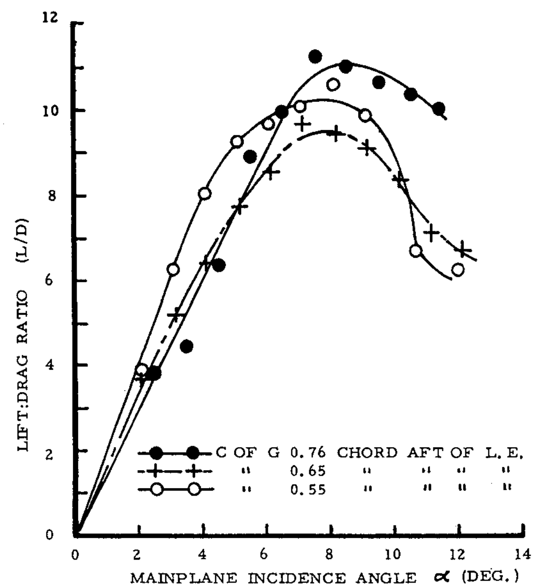

Fig. 6 Performance, in terms of L/D ratio, vs mainplane incidence angle of the wind-tunnel model OHS configuration. Reynolds number based on mainplane chord ≃ 6 × 10^4. Uncorrected wind-tunnel data.

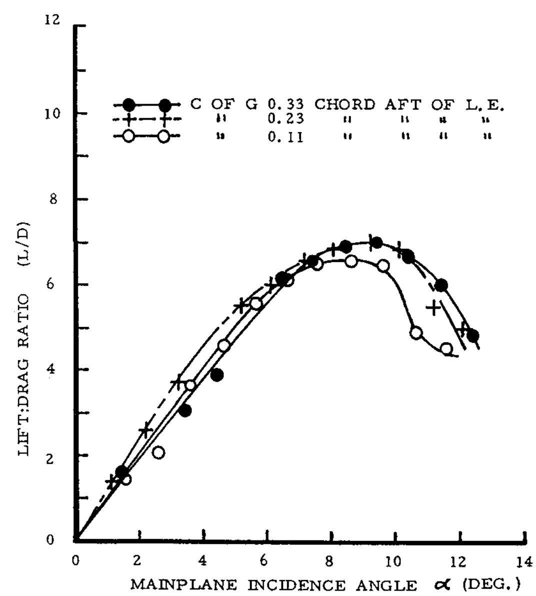

Fig. 7 Performance, in terms of L/D ratio, vs mainplane incidence angle of the wind-tunnel model conventional configuration. Reynolds number based on mainplane chord ≃ 6 × 10^4. Uncorrected wind-tunnel data.

Table 1 *L/D* ratios for equal lift (based on optimum *L/D* for conventional configuration)

Configuration	Corrected wind-tunnel results, $Re = 6 \times 10^4$	Predicted results, $Re = 6 \times 10^4$
OHS	9.122	8.661
Conventional	6.962	7.006
Σ drag (OHS)/ Σ drag (conventional)	0.763	0.809

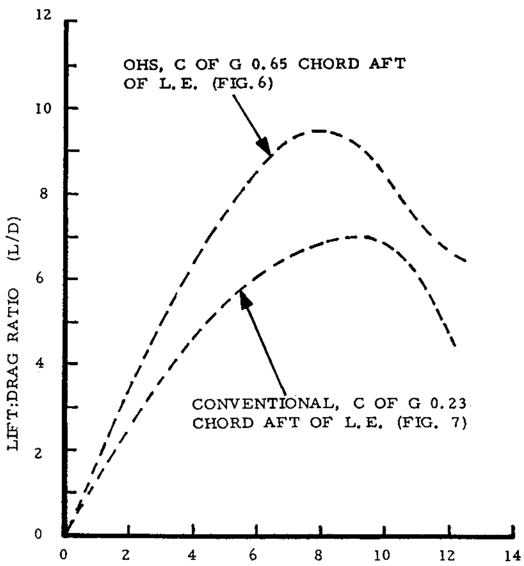

Fig. 8 Performance comparison, in terms of *L/D* ratio vs mainplane incidence angle, of the wind-tunnel performances of the OHS and conventional configurations. Uncorrected wind-tunnel data.

number, if the parasitic drags due to powerplants had been included, and if the model had been provided with a large cross section fuselage representative of a realistic transport.[2] An attempt was also made to establish an optimum setting of the vertical stabilizers of the OHS version of the model. It was only found to be possible to achieve a very small performance improvement by this means.

A comparison was made of the performances of the OHS and conventional versions of the model, for equal lift situations, based on the wind-tunnel test data corrected, using the methods recommended by Piercy,[7] to take into account the factors influencing the accuracy of these data. The predicted results also took into account a procedure, described by Hoerner,[8] for estimating the drag losses expected from the intersection of the tail-support boom with the wing suction surface of the conventional version of the model. The results of the performance comparison are presented in Table 1. It is worth noting that the experimental result for the OHS configuration may, possibly, be superior to the predicted value because flow inclined to the vertical stabilizers may generate a lift force, skewed to the line of flight, sufficient to offset the drag of these surfaces. When this assumption is applied to the prediction procedure, the OHS *L/D* increases from 8.661 to 9.193, and the predicted drag ratio is reduced from 0.809 to 0.762. The modified predicted values are then in almost perfect agreement with the experimental results.

Water-Tunnel Tests

Flow visualization tests were carried out in a water tunnel in which a small model of the OHS configuration was installed. The purpose of the tests was to obtain complimentary information to that obtained from wind-tunnel testing concerning local flow in the region of a mainplane tip and the adjacent horizontal, and vertical, stabilizer surfaces. The tunnel was of the vertical downflow type and followed a design originated by H. Werle of ONERA, France.[9]

The Reynolds number of the tests was unavoidably low due to the need to prevent turbulent mixing of the thin flow-visualization streams (condensed milk colored with food dye) in the main flow and around the model. As a consequence of this restriction the Reynolds number of the bulk flow in the transparent working section of the tunnel was approximately 7×10^3, whereas that based on the mainplane-chord of the model was only about 5×10^2. Despite these restrictions the tests did reveal upwash occurring outboard of the tip of the lifting mainplane, this flow then being deflected, rather as might be expected, by the projecting, adjacent, horizontal stabilizer surface. A strong inward flow deflection around the vertical stabilizers was also apparent. These tests served, therefore, to provide visual confirmation of the expected flow mechanism. They also served to provide partial justification for the modification to the OHS performance prediction procedure mentioned previously with respect to Table 1.

Free-Flight Models

Since neither the wind-tunnel nor water-tunnel models provided information relating to the controllability of OHS configurations, radio-controlled free-flight, powered, models were constructed to obtain practical experience in this area. The low-budget models were not instrumented; results were obtained by observations and pilot reaction. Four such models have been constructed and flown. The mainplane aspect ratios employed ranged from 4.5:1 to 8:1. Generally, an increase of aspect ratio will increase the mainplane effectiveness while reducing that of the horizontal stabilizer.[2] The model aircraft employed "fly-by-wire" systems with each electric-motor actuator installed close to the appropriate control surface. In each case the total planform area of the two-part horizontal stabilizer was approximately 40% of the mainplane area. The last three model aircraft were described, by their pilots as "easy to fly with good stability."

The fourth OHS model, of aspect ratio 8:1, was entered by the students of the Mechanical Engineering Department, who constructed it, in the 1993 Society of Automotive Engineers annual heavy-lift model aircraft contest. Accordingly, the model was built to conform to the contest rules that require, among other restrictions, the use of a specified 10-cm^3 (0.61-in.^{3}) engine in conjunction with an aircraft design in which the total planform area including hidden, or stacked, components did not exceed 0.775 m^2 (1200 in.^{2}). This model was placed fourth out of approximately 93 competing models in terms of the net load carried, and had nearly the same gross takeoff weight as the winner. This result was rather gratifying in view of the relatively large portion of the total surface area allocated to the horizontal stabilizer. This latter component cannot, because of the aircraft pitch-stability re-

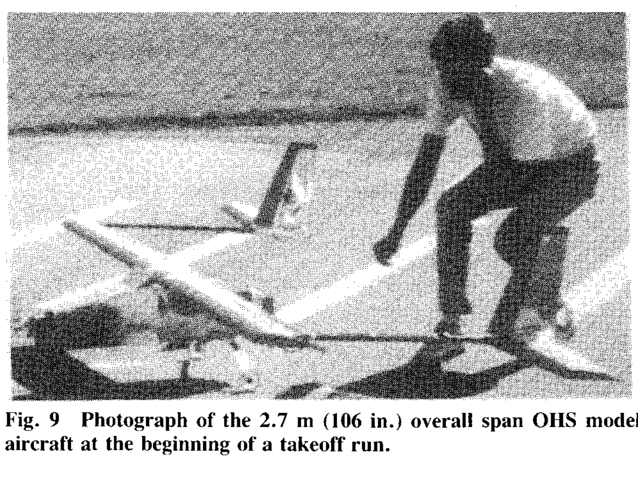

Fig. 9 Photograph of the 2.7 m (106 in.) overall span OHS model aircraft at the beginning of a takeoff run.

quirement, be so highly loaded as the mainplane. In fact, the geometry of the model implied that the maximum lift coefficient achievable by the horizontal stabilizer was about half that of the main wing with the vehicle in level flight. Figure 9 is a photograph of the fourth model aircraft. This model, which was of approximately 2.7 m (106 in.) span over the tips of the horizontal stabilizer, employed a Wortmann FX63-137 airfoil section for the main wing and horizontal stabilizer. The wing-chord-based flight Reynolds number was approximately $2.6 \times 10.^5$ It would appear probable that a greater net load could be carried using a design with a smaller horizontal stabilizer, and a c.g., closer to the main-wing c.p. than the 65% of chord aft of the main-wing leading-edge location employed on all the radio-controlled OHS model aircraft built to date.

Structural Loading Considerations

Perhaps the most controversial aspect of the OHS concept is the perception that such a configuration involves major structural problems. Evaluations were made, using simplified assumptions regarding the application to the structure of steady aerodynamic and gravitational loads, to establish for an OHS configuration the maximum wing torsional loading and also the wing-root bending moment. The loads evaluated in this way were normalized by dividing them by the corresponding loads occurring in a conventional aircraft employing a mainplane of the same span and aspect ratio as that of the OHS aircraft, and generating the same gross lift as the OHS aircraft.

It was assumed, for all lifting airfoil surfaces, that the aerodynamic lift was applied at the mean quarter-chord station. It was also assumed that for the conventional configuration the entire lift, equal to the gross weight of the vehicle, was provided by the mainplane. A consequence of this assumption was that the tail was (nominally) nonlifting, and hence, the c.g., of the aircraft lay, on the longitudinal centerline, at the wing quarter-chord station with the full gravitational load concentrated at this location. It was also assumed that the spanwise loading of the wing was elliptic and that the wing shear center was located 40% of the wing chord aft of the leading edge.

The corresponding assumptions for the OHS configuration were that 10% of the gross weight was attributed to the boom and tail assemblies (5% on each side of the aircraft), and that the local c.g. was located, in line with the appropriate wing tip, at a fore-and-aft location coincident with the mean quarter-chord station of the horizontal tail surface. The remaining 90% of the gravitational load was assumed to be located on the fore-and-aft centerline of the vehicle at an appropriate station ahead of the vehicle overall c.g. position. It was also assumed that the wing shear center was located at 50% of the wing chord aft of the wing leading edge. Both the mainplane and tailplane spanwise loadings were assumed to be elliptic.

Analytical results obtained for cantilevered configurations based on the foregoing assumptions are presented in Figs. 10–12. In all three diagrams the curves relate to the affect of varying the location of the c.g. of an OHS aircraft for which the horizontal stabilizer carries 20% of the total load when the c.g., is located 65% of the wing chord aft of the wing leading edge.

Figure 10 shows that the torsional loading of the wing is, as might be expected, sensitive to the location of the vehicle c.g. Careful inspection shows that at the 65% chord c.g. location the wing torsional loading, which is a maximum at the wingtips, exceeds the wing-root torsional loading of the conventional version of the aircraft by only about 17%; the corresponding wing-root torsional load is very small. This situation is the reverse of that applicable to the conventional configuration for which the maximum torsional loading occurs at the wing root. At a c.g. location of 50% of the wing chord, the maximum torsional loading of the OHS configuration occurs at the wing root and is equal in magnitude to that prevailing at the wingtip when the c.g. is at the 65% chord station.

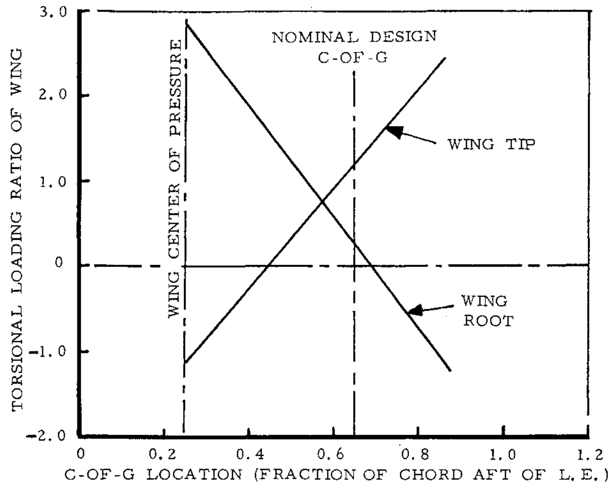

Fig. 10 Normalized steady torsional loading of the wing of an OHS aircraft vs c.g. location.

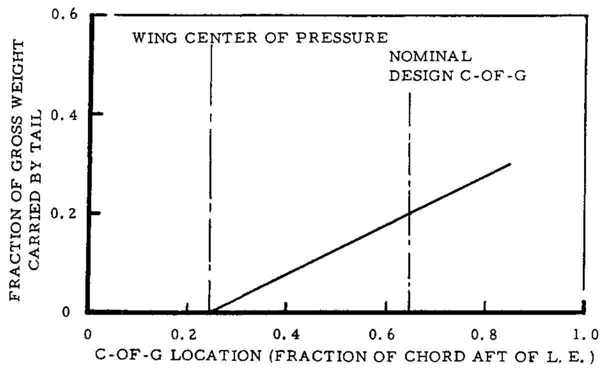

Fig. 11 Fraction of aircraft gross weight carried by outboard horizontal tail-surfaces vs c.g. location.

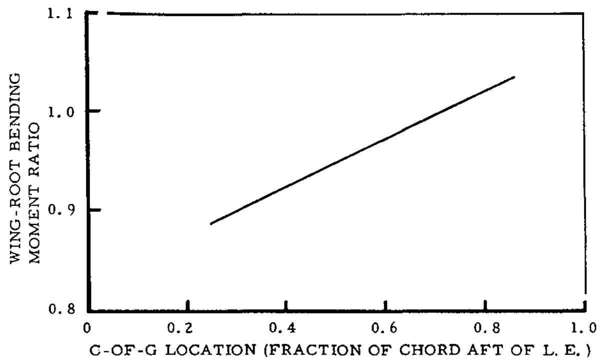

Fig. 12 Normalized wing-root bending moment of an OHS aircraft. Does not take account of (unquantified) loads acting on vertical stabilizers.

Figure 11 shows the fraction of the gross weight of the vehicle carried by the tail; it can be seen that with the c.g. located at 50% of the wing chord, the tail supports only 12% of the gross vehicle weight. However, this situation does not correspond to the most effective use, from the aerodynamic viewpoint, of the outboard tail arrangement since the tailplane is not operating at maximum efficiency.

It can be seen from Fig. 12 that the wing-root bending moment is not particularly sensitive to the c.g. location. The outboard weight of the tail-boom assemblies is helpful in offsetting the contribution to wing-root bending moment of the outboard, lifting, tail surfaces. The wing-root bending moment of the outboard horizontal stabilizer configurations is approximately the same as that of a corresponding conventional design.

It can be seen, from Figs. 10 and 12, that it appears to be feasible for the c.g. to range between 45 and 70% of the wing chord, provided that wing torsional loads up to 50% in excess of those of a conventional aircraft are acceptable. This range of c.g. variation, 25% of the wing chord, is far greater than the range of 10% typical of conventional aircraft.[6] The 10% range of c.g. locations representative of conventional aircraft is dictated, essentially, by aerodynamic considerations.[6] The 25% range suggested for the outboard horizontal stabilizer aircraft appears to be compatible with the requirements of stability in pitch, and hence, seems to be feasible aerodynamically with the most efficient operation of the vehicle occurring when, for the design considered here, the c.g. is 65% of the chord aft of the wing leading edge.

An elementary design exercise showed that the torsional loading of simple, tubular, tail booms, of reasonable diameter, for an OHS aircraft did not present a significant stress, and hence, weight problem. This result was due, essentially, to the excellent resistance to torsional loading inherent in tubular structures.

Development Potential

The OHS configuration lends itself, particularly for propeller-driven aircraft, not only to single-engine tractor or pusher arrangements, but also, quite naturally, to centerline twin-engine propulsion systems that avoid trim-asymmetry during engine-out operation. Generally, due to the requirements of ground clearance associated with takeoff and landing, an OHS arrangement is perceived as most suitable for high-wing aircraft. Also, because of the relatively high-polar moment of an OHS configuration about the longitudinal axis of symmetry the arrangement is not well-suited for highly maneuverable or aerobatic aircraft. Hence, any further development should, it appears, be focused on transport-type applications.

Due to the vortices shed from the outboard tips of the horizontal stabilizer being augmented by upwash from the main wing, it should prove desirable, from the aerodynamic performance viewpoint, to add winglets to the outboard tips of the horizontal stabilizer of an OHS configuration. Such winglets are now fairly commonly applied to the mainplane tips of conventional aircraft.

Another possible line of development of the OHS concept could be to dispense with the vertical stabilizers and employ, at the downwind tip of each boom, a single tail surface with substantial dihedral or possibly, ground clearance permitting, anhedral. Such an arrangement eliminates the intersection of two airfoil surfaces at the junction of each horizontal and vertical stabilizer of the configuration shown in Fig. 1. The "single-surface" tail places much reliance on the counter-rotating vortex situation at the inboard end of each single tail surface to replace the end-plate function of the vertical stabilizers shown in Figs. 1, 3, 5, and 9. The single-surface tail also requires differential operation of the "elevators" to simulate a rudder action.

Adaptation of the OHS configuration to high subsonic Mach numbers suggests the use of swept wings. The wings should be swept forward to avoid structural divergence problems for an OHS aircraft with swept wings, an opposite situation to that for conventional aircraft. Thus, a forward-swept OHS configuration is able to take advantage, quite naturally, of an aerodynamically more efficient wing planform than a conventional aircraft. Although forward sweep weakens the tip vortices formed by a lifting wingtip, upwash is still available to assist the operation of the adjacent portion of the outboard horizontal-stabilizer surface.

Conclusions

A description has been given of what is believed to be an innovative aircraft configuration featuring outboard horizontal stabilizers. It was shown theoretically that such a tail surface is more effective, from the pitch-control viewpoint, than a conventional horizontal tail influenced by the wing downwash. It has also been shown, primarily as the result of wind-tunnel testing of models supported by predictive analysis and flow visualization tests, that an OHS system can contribute, efficiently, to lift. The contribution to lift occurs without a corresponding increase in drag, thereby yielding an increase in aircraft L/D ratio, up to about 30% for $A_W \simeq 6$, compared with an otherwise comparable conventional aircraft. Free-flight testing of large, radio-controlled, powered, model OHS-type aircraft has confirmed that the new configuration does not present significant problems related to flying qualities. It was also shown, at the level of an elementary steady-loading analysis, that a properly designed OHS configuration does not give rise to major structural difficulties.

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