Comparative Analysis of Effects of Hover Control Concept on V/STOL Aircraft Size

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The design of a minimum size V/STOL aircraft to meet given mission requirements is directly influenced by the hover control concept selected and the control power requirements. Parametric studies were conducted on a lift-plus-lift-cruise variable sweep V/STOL fighter aircraft to indicate the aircraft weight penalty and control effectiveness associated with various hover control arrangements. These studies evaluated the effectiveness of three basic control systems: 1) engine bleed, 2) thrust modulation, 3) combined bleed and thrust modulation. Engine bleed systems included bleeding lift engines only, bleeding lift cruise engines only, or bleeding all engines. Both continuous and demand bleed systems were studied. Twenty control arrangements were evaluated for the normal power hover flight condition. Using unique digital computer models, aircraft size, engine size, and control effectiveness were parametrically determined as a function of percent engine bleed, vertical lift-to-weight ratio at takeoff, and hover control power requirements. Data was obtained for both single-axis and simultaneous three-axis hover control power maneuver requirements. Comparison of the effectiveness of each control arrangement clearly indicated the most efficient system, i.e., one yielding a minimum size vehicle meeting both mission and hover control power requirements.

Nomenclature

F_N = total installed vertical thrust including bleed reaction forces
$F_N{}^*$ = maximum uninstalled sea-level static standard day thrust
L = total system lift including bleed reaction forces, if any
n = number of engines
TL = thrust loading
W = design takeoff weight

Subscripts

L = lift engine
LC = lift-cruise engine

I. Introduction

THE selection of the subaerodynamic control concept is a prime consideration in the preliminary design of V/STOL jet aircraft. The aircraft size, performance, control effectiveness, and even the feasibility of a desired configuration can be dependent on the system selected.

With the advent of the composite lift-plus-lift-cruise engine V/STOL aircraft designs, it is now necessary to evaluate the effectiveness of three basic control concepts before selecting the best for the aircraft design. These concepts are 1) engine bleed only, 2) thrust modulation only, or 3) combined engine bleed and thrust modulation. The problem is made additionally complex, since with the bleed concept, either the lift, the lift-cruise, or all engines can be bled. Also, the system employed can be either a continuous, a demand, or a continuous plus demand bleed system with any mix of reaction jet control locations. To systematically evaluate all of the variables and select the most efficient control concept, a unique hover control and aircraft sizing methodology has been developed and used at Republic in all V/STOL aircraft studies.

The purpose of the present paper is to outline this sizing methodology and to summarize the results of a hover control comparative analysis performed on a typical V/STOL fighter bomber using the lift-plus-lift-cruise propulsion concept. The effects of hover control concept, bleed system, and type of bleed control on aircraft size and control effectiveness for twenty control arrangements were evaluated, and results for the best of these compared.

II. Aircraft Sizing Methodology

The data presented in this paper are based on results obtained from digital computer models developed at Republic over the past five years. For the comparative analysis of hover control concepts to be considered herein, three computer models are used: aircraft sizing, three-axis moment of inertia and balance, and hover flight control synthesis.

Each of these models is designed to provide the desired data for any lifting propulsion system concept (lift-fan, lift-cruise, or composite systems) as a function of cruise engine size, aerodynamic geometry (w/s, AR, t/c, etc.), and structural design parameters (load factor, materials, subsystem packaging) for either fixed or variable sweep-wing concepts. Extensive application and subsequent configuration design analyses have proven the technical accuracy of these models even to the extent of indicating where an actual configuration layout could be improved as predicted by the computer models.

Although a detailed presentation of model logic is beyond the scope of this paper, a brief description of each model is presented in the following section to provide background data for the reader. Additional information describing model logic and analysis techniques are presented in Refs. 1–4.

Aircraft Sizing Model

This model basically determines the aircraft size (VTO weight, length, density, etc.) as a function of cruise-engine thrust loading required to meet a prescribed set of mission

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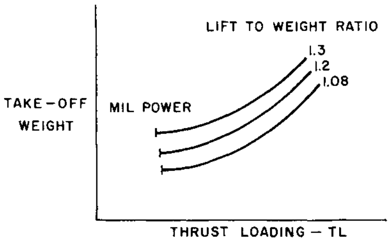


Fig. 1 Representative sizing results.

requirements and aerodynamic and structural geometry. Cruise-engine thrust loading is defined as the maximum uninstalled sea-level standard day horizontal thrust divided by the aircraft takeoff weight. Therefore,

$$TL = n_{LC}F_{NLC}^*/W$$

The use of thrust loading as a sizing variable provides a direct indication of the effect of cruise mode powerplant mixmatch resulting from engine sizing to meet nonmission requirements, e.g., high speed, acceleration, short takeoff, etc.

It can be analytically shown for all lifting concepts (lift fan, lift plus cruise, lift plus lift cruise, lift cruise) that engine thrust and fuel flow for any operational condition can be expressed in terms of the thrust loading parameter. A typical illustration for a lift-plus-lift-cruise composite V/STOL propulsion concept is indicated by the simple relationship for

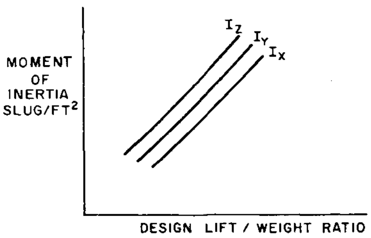


Fig. 2 Representative inertia data output.

the total lift produced by the system:

$$L/W = \underset{\text{lift engine}}{n_L(F_N/F^*_N)_L(F^*_N/W)_L} + \underset{\text{lift cruise}}{(F_N/F^*_N)_{LC}(TL)_{LC}}$$

It is noted that with a given cruise engine size (F_N/F^*_N) (TL) = const, the extra lift to weight (L/W) required to satisfy control, suckdown, hot-gas ingestion, or vertical acceleration criteria is always charged directly to the lift engine F^*_N. Similar expressions for other lifting systems are presented in Refs. 2 and 4.

The structural subroutine in the sizing program determines the weight empty, and hence fuel available, for mission performance as a function of VTO weight and thrust loading. Component weight items are defined as functions of engine scaling parameters, aerodynamic geometric parameters, fuselage packaging, and material selection parameters. Component weight subroutines were derived for the propulsion system, wing, fuselage, landing gear, empennage, useful load, subsystems, and controls. Engine arrangement logic includes wing nacelle, side fuselage mounting, and internal fuselage installation concepts. In the controls system logic, weight, and volume allowances for the bleed air ducting are computed as a function of aircraft length for the pitch control piping and wing span for the roll control piping. In addition to component and total structural weights, the data ouptut includes: component-wetted areas, net cross-section area, equivalent airplane fineness ratio, airplane length, and number, size, and location of lift engines. All aircraft are so balanced that the center of lifting thrust is located at the center of gravity.

Table 1 Single-axis minimum initial angular accelerations

Axis	Angular acceleration, rad/sec²
Roll	1.2
Pitch	0.6
Yaw	0.4

The fuel required for mission performance is subsequently determined from a general mission subroutine using standard drag analysis procedures with skin-friction drag based on component-wetted areas obtained from the structures subroutine. Installed propulsion performance data input is nondimensional in format (F_N/F^*_N) and, for specified design lift-to-weight ratios (L/W), enables engine scaling by multiplying the propulsion data by thrust loading. Aircraft size is determined by the matching of fuel available and mission fuel required as a function of thrust loading and design lift to weight for the aerodynamic and structural configuration under consideration. A typical presentation of the sizing results is indicated in Fig. 1.

For a given lift-to-weight ratio, the minimum-weight aircraft occurs at the thrust loading for the military power setting. Actual design thrust loading is determined from other flight performance requirements, e.g., maximum speed at altitude, short takeoff, turn maneuvers, acceleration, etc. The design lift-to-weight ratio can be determined by hover, transition, or engine failure flight control requirements using the control synthesis model. The results obtained from the sizing model represent inputs for the moment of inertia and balance model.

Moment of Inertia and Balance Model

Logic for this model conforms with standard procedures for computing mass properties of aircraft. The model computes aircraft c.g. and moment of inertia about three axes, the center of vertical lift for V/STOL aircraft, and the rotation of the principal axes and principal moments of inertia. The model is designed to evaluate aircraft for both parametric and "frozen" designs. For parametric studies, weight input data are derived from the basic sizing program previously discussed. The input for component c.g. locations is selected from an extensive library of conceptual configuration layouts. Inertia data output for hover control system studies are generated as indicated by the format in Fig. 2. These results, together with the corresponding aircraft weight (Fig. 1) and propulsion performance data represent the inputs for the hover flight-control synthesis model.

Hover Flight-Control Synthesis Model

The hover flight-control synthesis model is designed to evaluate a large variety of lift propulsion and control concepts. Any arrangement and number of propulsive devices of any one type or a mix of any two types, i.e., lift fan, lift

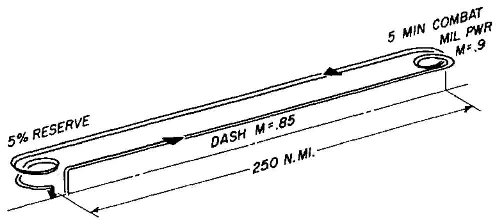


Fig. 3 VTOL Lo-Lo-Lo mission profile.

Table 2 Reaction control nozzle locations

	% of fuselage length		% of wingspan
	Forward of c.g.	Aft of c.g.	Outboard of ℄
Fuselage	34.3	40.1	...
Wingtip	...	11.6	44.3

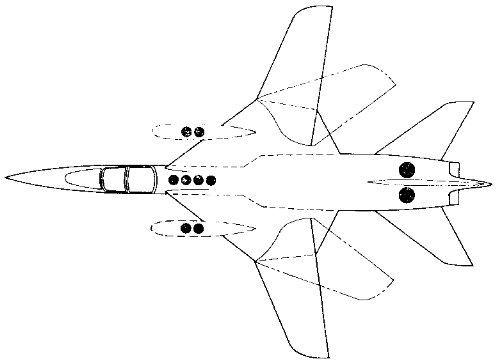


Fig. 4 Typical variable sweep configuration, lift engines in fuselage or nacelles.

plus cruise, etc., can be considered. Thrust modulation and/or vectoring of the primary lifting thrust and/or compressor-bleed reaction controls are the basic control concepts. Bleeding can be on a continuous and/or on a demand basis from either one or a mix of two types of engines. The reaction device may or may not be augmented by such devices as bleed burning, control fans, or ejector nozzles. A single reaction control nozzle may be located at each extremity of the aircraft or doubled up in almost any combination if two separate bleed air sources are used. Continuous and demand bleed-reaction systems may use the same nozzle or may use separate nozzles. For yaw control, any or all reaction nozzles may be swiveled (vectored control force) or separate horizontal force nozzles may be used. With the exception of yaw control forces, all reaction forces act in the lift direction.

Seven aircraft maneuver phases can be analyzed individually or simultaneously. These maneuver phases are 1) trimmed about all axes; 2) nose-down pitch acceleration, trimmed in roll and yaw; 3) nose-up pitch acceleration, trimmed in roll and yaw; 4) roll acceleration, trimmed in pitch and yaw; 5) yaw acceleration, trimmed in roll and pitch; 6) simultaneous nose-down pitch, roll and yaw acceleration; and 7) simultaneous nose-up pitch, roll and yaw acceleration. The initial vertical acceleration during any of the seven maneuver

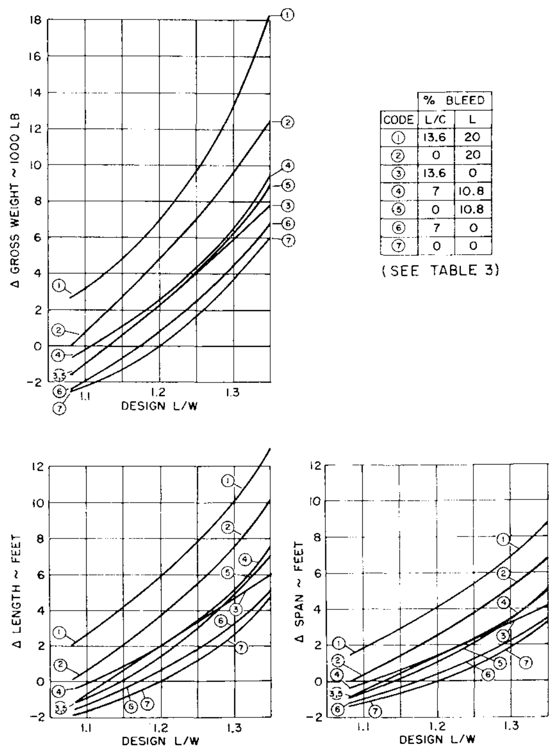


Fig. 5 Aircraft weight variation with continuous bleed concept.

phases can be specified as zero (hover), or any positive or negative value within the capability of the subject aircraft, or can be solved for as a function of the specified power levels and weight. The model may be applied to any desired condition such as VTO, hover, landing, engine failure, or subaerodynamic flight.

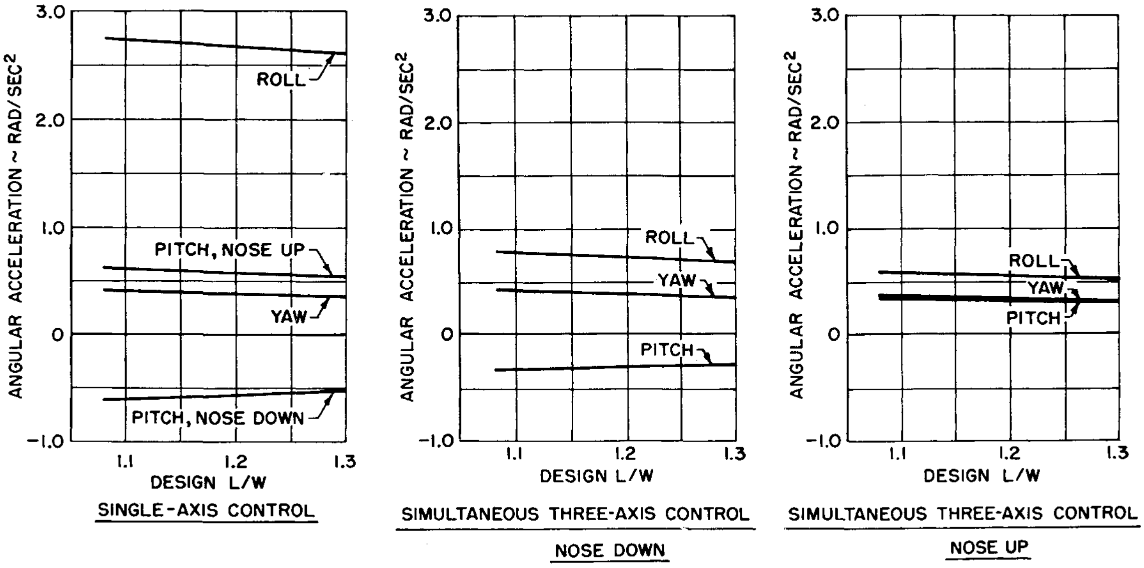
III. Sizing Data and Design Criteria

Using the methodology previously discussed, hover control system studies were performed based on the control criteria requirements and specific design data outlined in this section.

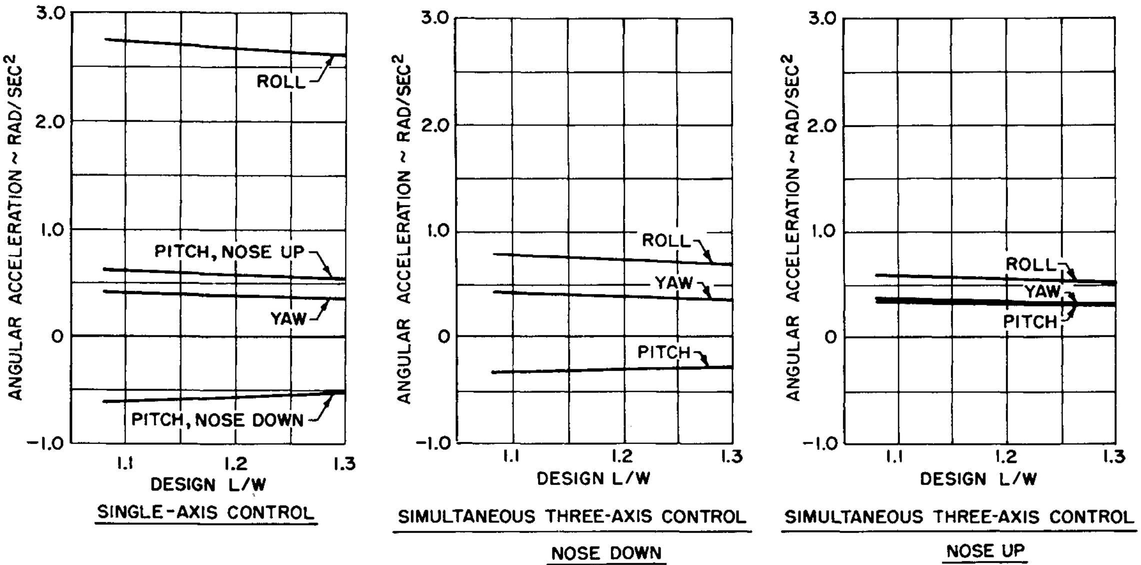
Table 3 Control system description and source of compressor bleed air for reaction control jets

				Bleed air source		
				Pitch jets		
Control system	Maneuver			Fuselage		Roll jets
no.	Pitch	Roll	Yaw	Fwd	Aft	Wingtips
1	Reaction jets	Reaction jets	Reaction jets ± 45°	L[a]	L	L
2				L/C[b]	L/C	L/C
3				L	L	L/C
4				L/C	L/C	L
5				$L + L/C$	L	L/C
6				$L + L/C$	L/C	L
7				L	$L + L/C$	L/C
8				L/C	$L + L/C$	L
9				$L + L/C$	$L + L/C$	L/C
10				$L + L/C$	$L + L/C$	L
11				L	L	$L + L/C$
12				L/C	L/C	$L + L/C$
13				L/C	L	$L - L/C$
14				L	L/C	$L + L/C$
15				$L + L/C$	$L + L/C$	$L + L/C$
16	Thrust modulation		Thrust vectoring ± 15°	None	None	L
17				None	None	L/C
18	Reaction jets	Thrust modulation		L	L	None
19				L/C	L/C	None
20	Thrust modulation			None	None	None

[a] L = Lift engines.
[b] L/C = Lift-cruise engines.



a) Control system 10, for c and d, ϕ = critical point, all minimum requirements satisfied; maximum continuous bleed, all engines



b) Control system 15, maximum continuous bleed, all engines

Fig. 6 Hover control power vs design L/W.

Propulsion System

The lift engines considered represent current state-of-the-art (high thrust-to-weight and high pressure ratio technology) engines designed for rapid response and having a compressor-bleed air capability up to 20% of engine air flow. The engines are assumed to have simple bellmouth inlets designed to provide an average pressure recovery of 97%.

The lift-cruise engine considered is a high pressure ratio, moderate bypass ratio engine with a maximum compressor-bleed flow rate of 13.6%. An inlet pressure recovery of 95% is assumed.

The engines were considered to be operating at or below the design turbine inlet temperature. Engine overtemperature operation was assumed to be restricted to emergency operations and is therefore not evaluated in the present study.

Mission Performance

All aircraft are sized to meet a low level, $M = 0.85$ dash requirement with a radius of 250 naut miles. The vertical takeoff and landing phase corresponds to operation at a 2000-ft altitude and 90°F ambient condition. The mission profile is indicated in Fig. 3.

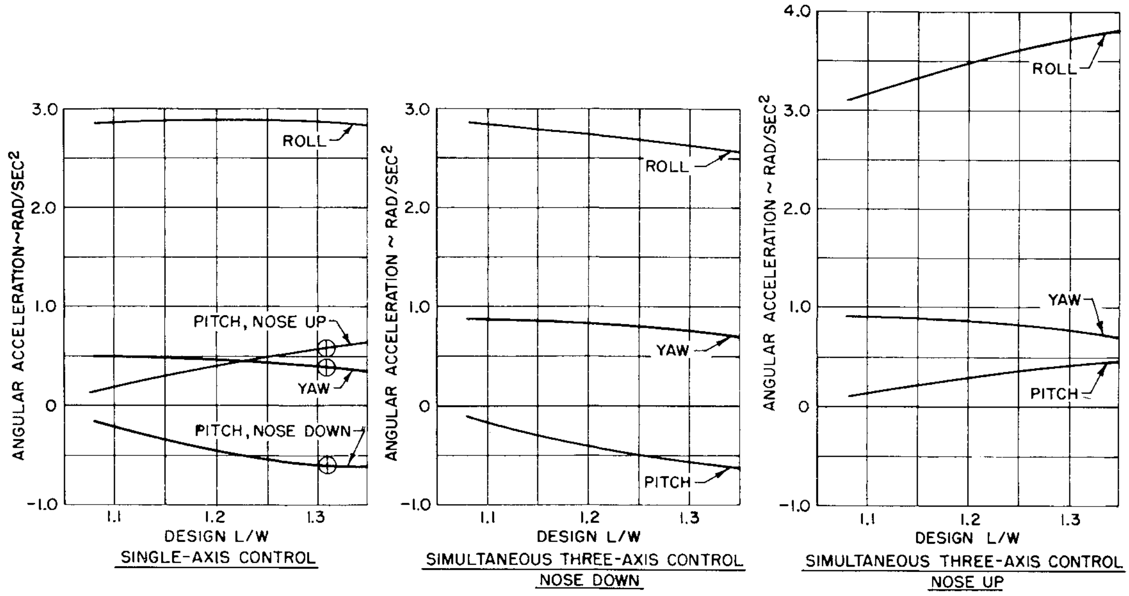
Hover Control Criteria

Each control concept evaluated in the study is required to meet the following single-axis minimum initial angular accelerations for all aircraft weights and inertias, as shown in Table 1.

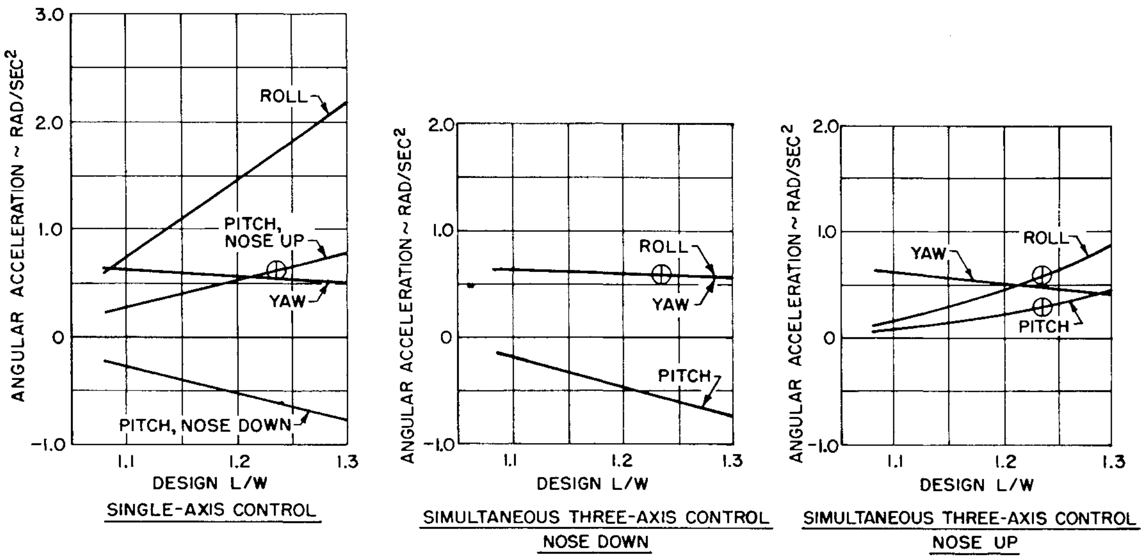
In addition, each system must be capable of providing at least 50% of the single-axis minimum control power about all axes as a simultaneous control requirement. These requirements are based on a clean configuration in a hover mode ($T/W = 1.0$) out of ground effects at a 2000-ft altitude and 90°F ambient condition and after all allowances for trim are made.

IV. Configuration Design

The hover control comparative analysis is based on a representative variable sweep V/STOL fighter bomber, as il-



c) Control system 16, maximum continuous bleed, lift engines



d) Control system 20, thrust modulation

Fig. 6 (Continued)

lustrated in Fig. 4. The lifting concept is a composite system using lift-cruise engines and lift engines. The aircraft has a design wing loading of 100 psf and a wing aspect ratio of 6 based on the theoretical wing area in the extended position. Aircraft length, weight, and wing span vary with the control systems considered and are indicated in Sec. VI of this paper. All sizing studies are based on a cruise engine size corresponding to a thrust loading of 0.5 to provide satisfactory flight performance. The control system analysis considers two installation arrangements for the lift engines in the reference aircraft. In one arrangement, the lift engines are installed in line in the fuselage forward of the c.g. The second arrangement has one row of two rotatable lift engines installed horizontally in a streamlined nacelle mounted on and extending forward of the fixed stub of the variable sweep wing. For VTOL and transition flight, these engines are rotated in the nacelle to the vertical position. This configuration is used only to provide roll control with the thrust modulation concepts. All other analyses consider the fuselage installed lift engine arrangement. The lift cruise engines are located side by side in the aft fuselage. The fore and aft locations of all engines are varied in the sizing methodology as a function of design lift-to-weight ratio and continuous engine bleed levels so that the engine thrust trims the airplane about all axes. For the bleed-control studies, reaction control nozzles are located in the forward and aft fuselage and wing tips. Their location, in percent of airplane length or wing span, is constant in all studies and corresponds to the data presented in Table 2.

V. Hover Control Concepts Analyzed

The relative effectiveness of three basic hover control concepts is evaluated in the analysis. These concepts are engine bleed only, combined thrust modulation and engine bleed, and thrust modulation only.

With each of these engine bleed arrangements, the effect of three types of bleed concepts on aircraft size is also evaluated

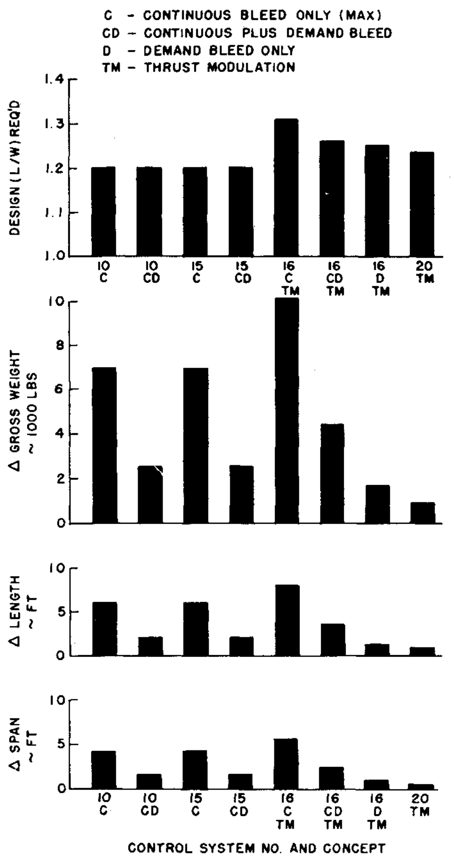


Fig. 7 Incremental gross weight and size at required design L/W ratios.

as a function of percent bleed air. These bleed concepts are continuous, continuous plus demand, and demand.

Although bleed burn augmentation systems have been evaluated in other studies by Republic and other investigators,[5] consideration of such concepts is not treated in the present analysis.

The 20 hover control systems described in Table 3 were selected for evaluation. These systems are identified within the three basic hover control concepts as: 1) engine bleed air reaction control jets only (control systems 1–15), 2) combined thrust modulation plus engine bleed reaction control jets (system 16–19), and 3) thrust modulation only (system 20).

The reaction control systems and partial reaction control systems were analyzed for three compressor bleed arrangements: 1) maximum continuous bleed of all engines, 2) partial continuous bleed plus demand bleed to maximum of all engines, and 3) demand bleed only to maximum of all engines. Reaction control nozzles are nominally down-blowing to augment lift. To produce yawing moments, the nozzles are swiveled to 45° antisymmetrically rather than using separate side-facing nozzles. This design approach increases the control moments available for the simultaneous roll, pitch, and yaw control condition.

With the combined thrust modulation and bleed systems (control systems 16–19), two approaches are considered; the first uses thrust modulation for pitch control with lift-cruise- or lift-engine bleed for roll control (systems 16, 17), and the second uses thrust modulation for roll control and lift-cruise- or lift-engine bleed for pitch control (systems 18, 19). The three-axis control with the thrust-modulation-only concept is control system number 20. In each of the systems using partial or total thrust modulation, control about the yaw axis is based on exhaust gas thrust vectoring on all engines. The forward and aft engines vector exhaust gas sidewards antisymmetrically, 15° from the vertical.

VI. Effect of Hover Control Concept on Aircraft Size

Using the sizing methodology in conjunction with the reference configuration design and propulsion data previously discussed, aircraft VTO weights which satisfy the 250-naut-mile mission requirement have been determined for the hover control concepts analyzed. The reaction control bleed levels considered include maximum continuous bleed, partial continuous bleed, and zero bleed on all engines. The zero bleed condition also represents the control concept for a demand-only bleed system, or a thrust-modulation system, or the combined demand-bleed and thrust-modulation system. The bleed air magnitudes used in the study are summarized in Table 4.

The partial continuous bleed levels represent the continuous magnitudes used for the continuous plus demand system. The demand continuous bleed level and the design maximum continuous bleed for the engine considered.

Aircraft weight variation with design lift-to-weight ratio is presented in Fig. 5 for the engine continuous bleed magnitudes indicated in Table 4. Length, wing span, and the moments of inertia follow the same trends. All results are presented as incremental values relative to the data obtained for a control system with zero continuous engine bleed at a reference 1.2 lift-to-weight ratio. The data for the aircraft sized at the reference 1.2 lift-to-weight ratio are indicated in Table 5 and represent characteristics for 45,000-lb weight class aircraft. As indicated in Fig. 5, the reaction control concept with maximum continuous bleed on all engines has the greatest effect on the aircraft size; the zero bleed (or all demand, or all thrust modulation) concept has the least effect. The final step in the sizing methodology is to determine the lift-to-weight ratio required to satisfy the hover control criteria indicated in Sec. III.

VII. Effectiveness and Comparison of Hover Control Concepts

The data presented in this section represent the control effectiveness and sizing results for several of the 20 control systems analyzed. In the interests of brevity, results are shown only for those systems which nominally satisfied the hover control criteria specified in Sec. III. Referring to Table 3, these systems are 10, 15, 16, and 20.

Figures 6a–6d present each of these selected configurations separately showing single-axis and simultaneous three-axis angular accelerations as a function of design lift-to-weight ratio. Only continuous bleed is shown in these figures in order to illustrate the methods used; the control effectiveness with continuous plus demand bleed system yields similar results. The engines have been slightly moved fore and aft relative to the c.g. to obtain approximately equal nose-up and nose-down pitch capability. The results indicate the existence of a critical design lift-to-weight ratio which is de-

Table 4 Engine continuous bleed air flow magnitudes

Bleed control	Continuous bleed air flow ~ %		Code no. Fig. 5
	Lift cruise	Lift	
Maximum continuous bleed	13.6	20	(1)
	13.6	20	(3)
	0	20	(2)
Partial continuous bleed	7	10.8	(4)
	7	0	(6)
	0	10.8	(5)
All demand, or all thrust modulation, or combined demand bleed plus modulation	0	0	(7)

fined as the lowest design lift-to-weight at which all of the control criteria are met or exceeded. In no case, however, will the selected value be less than 1.2 in order that height control in hover remains adequate.

With control system 10, Fig. 6a, the single-axis roll control effectiveness exceeds the 1.2 rad/sec² criteria for all lift-to-weight ratios. The control power available in pitch meets its ± 0.6 requirement at $L/W \leq 1.12$. The yaw requirement of 0.4 is satisfied at $L/W \leq 1.14$. The nose-down simultaneous axis roll and yaw exceed their respective 0.6 and 0.2 rad/sec² requirements, whereas pitch is satisfied at $L/W \leq 1.2$. For nose-up simultaneous axes maneuvers, roll control is critical and does not meet the requirement above $L/W = 1.08$. A design lift-to-weight ratio of 1.2 is recommended for this control system for height control, even though slight control deficiencies result in single axis pitch and yaw, as well as nose-up simultaneous axis roll.

Figure 6b shows the corresponding control effectiveness for control system 15. The control power is seen to be identical for control systems 10 and 15, indicating that the lift-cruise engine bleed reaction jet in the wing tip of 15 is ineffective. This occurs in both the single-axis and the simultaneous three-axis maneuver because the total roll force available (after the fuselage jets are supplied with bleed air for trimming or maneuvering) is less than the lift engine bleed air available. Again, a design lift-to-weight ratio of 1.2 is chosen as a minimum acceptable level for good height control.

Noteworthy in Figs. 6a and 6b is the lack of substantial effect on control power resulting from L/W increase. This illustrates the cancelling effect of increasing inertias on the increasing reaction control bleed air available for the heavier airplanes with high magnitudes of L/W.

The effectiveness of the bleed plus modulation system 16 is summarized in Fig. 6c. Thrust modulation is used for pitch control and the expected increase in control power with design lift-to-weight ratio is determined. At a lift-to-weight ratio of 1.31, the single-axis nose-down and nose-up pitch and yaw are equal to the requirements; all other maneuver requirements are exceeded.

For the all-thrust-modulation system 20 data as presented in Fig. 6d, the critical design lift-to-weight ratio occurs at 1.235 where the simultaneous three-axis nose-down and nose-up roll, and nose-up pitch, are satisfied, with all other requirements being exceeded.

Similar results using continuous-plus-demand-bleed and demand-bleed-only concepts have been evaluated and are included in the comparison data presented in the next section.

Table 5 Reference aircraft data[a]

VTO weight, lb	45,000
Length, ft	71
Span, ft	50
Inertia slugs, ft², I_x	32,900
I_y	226,100
I_z	247,800

[a] Corresponds to control system 20 at $L/W = 1.2$.

Control System Comparison Summary

A summary comparison of the effect on aircraft size and control effectiveness for the most efficient control systems is presented in Figs. 7–9. The control systems and bleed concepts selected are those which nearly meet, meet, or exceed the control criteria presented in Sec. III. These systems are control systems 10, 15, and 16 with continuous and continous-plus-demand bleed concepts, control system 16 with demand bleed only, and control system 20 with thrust modulation only.

The control system yielding the heaviest aircraft is number 16. It uses thrust modulation in pitch and continuous lift engine bleed for roll control. This system requires a design

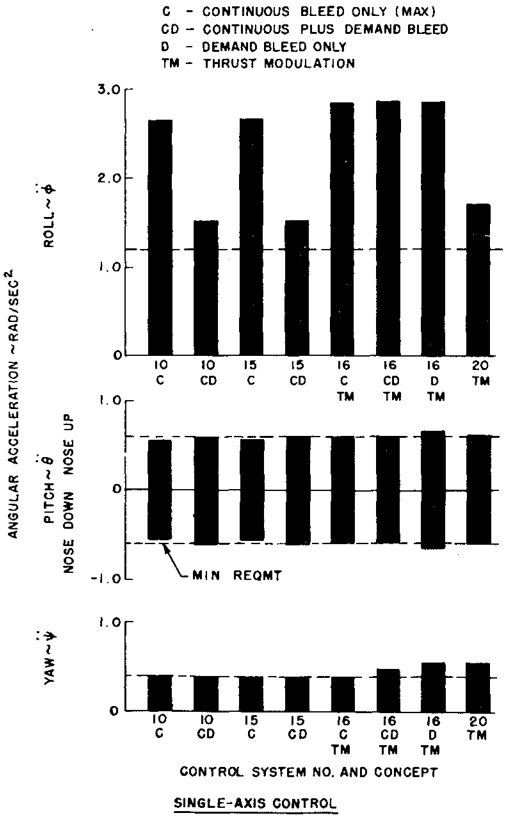


Fig. 8 Single-axis control power at required design L/W ratios.

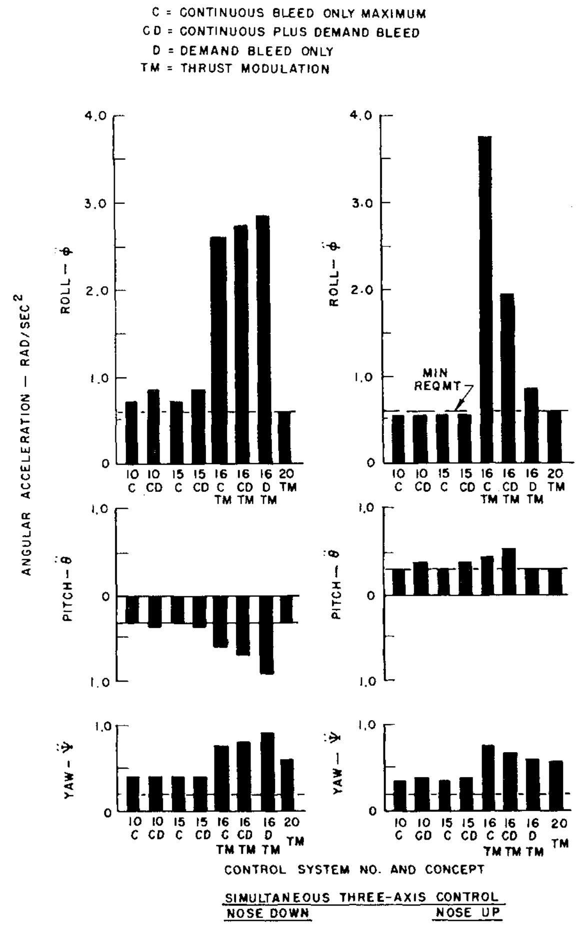


Fig. 9 Simultaneous three-axis control power at required design L/W ratios.

lift-to-weight ratio of 1.31, and is 10,100 lb heavier, 8 ft longer, and has 5.5 ft more wing span than the reference airplane (Table 5). The control system yielding the lightest aircraft is the all-thrust-modulation system, number 20. This system requires a design lift-to-weight ratio of 1.235 and is 850 lb heavier, 0.8 ft longer, and has 0.5 ft more wing span than the reference airplane. The next lightest aircraft control system is number 16 (using demand lift engine bleed). This system yields an aircraft which is 1700 lb heavier than the reference airplane. The lightest aircraft designed with a reaction control system is either number 10 or 15, using continuous plus demand all engine bleed. The incremental gross weight of these systems is 2550 lb. For the three control systems, 10, 15, and 16, the continuous bleed concept yields the heaviest aircraft.

Figure 8 presents the single-axis roll, pitch, and yaw control power of the selected control systems. The roll requirement is generously exceeded by all control systems, pitch is nominally satisfied by all, and yaw is nominally satisfied or exceeded by all. Figure 9 presents the control power available for simultaneous three-axis maneuvers. All the control criteria are met or exceeded by all control systems except 10 and 15, which are slightly deficient in roll for the nose-up maneuver.

VIII. Conclusions

In conclusion, it should be noted that, although the results of this study indicate that the thrust-modulation-only system is clearly superior from an aircraft sizing standpoint, this result is directly affected by the control criteria chosen, the engine mix, the engine locations, and the weight-inertia relationships. A significant change in any of these factors necessitates a complete re-evaulation of the zero-speed control system and airplane sizing interface. In the selection of another system, however, a number of practical considerations which favor thrust modulation, as opposed to an engine bleed air control system, should be evaluated. These considerations are: 1) use of the existing engine package with only minor modifications for control; 2) a gain in usable internal volume by eliminating long, large diameter bleed pipes; 3) reduced zero-speed control system vulnerability to small arms fire by eliminating long bleed pipes in wings and fuselage; 4) reduced complexity because the eliminated control nozzles and bleed pipes do not conflict with the basic airplane design in nose wheel compartments, equipment bays, cockpit areas, engine envelopes, thin wing sections, and wing pivot points (in the case of variable sweep designs); 5) increased instead of decreased potential control power while landing at low gross weights, since the available thrust margin is increased (whereas control with bleed air is decreased) at lowered power settings; and 6) a possible advantage in an engine failure situation, since an emergency trim system could probably be incorporated in the basic control system.

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