GENERAL ARRANGEMENT COMPARISON

GII vs GII(S)

WING AREA ~ SQ FT  800
SPAN ~ FT  68'10"
SWEET 1/4 CHORD  25°
ASPECT RATIO  6.0
THICKNESS RATIO  12% ROOT
                 8.5% TIP
DIHEDRAL  3°
INCIDENCE  1.5°

820
68'10"
42°
5.9
12% ROOT
8.5% TIP
3°
1.5°
AREA DISTRIBUTION COMPARISONS

42° A SUPERCRITICAL WING GII vs CURRENT GII

CROSS-SECTIONAL AREA

FUSELAGE STATION ~ FT.

WING

FUSELAGE

ENG., NACELLE, & PYLON

FIN

STAB

GII

CAPTURE AREA REMOVED

WING + FUSELAGE

ENG + MC

VERT. TAIL

HORIZ. STAB.

GII(S)

11-20-70
DRAG DIVERGENCE MACH NUMBER
BASED ON AREA DISTRIBUTION

GULFSTREAM 2 WHITCOMB WING DEMONSTRATOR
NOSE COMPONENT FINENESS RATIO

DRAG DIVERGENCE MACH NO.

LOWEST COMPONENT EFFECTIVE FINENESS RATIO
DRAG COEFFICIENT COMPARISON
42° A SUPERCRITICAL WING GII vs CURRENT GII

$C_L = 0.4$

$C_L = 0$

$C_T$ @ 40,000 FT. MAX CONTINUOUS PWR
$S_w = 800$ FT$^2$

MACH NO.
PERFORMANCE COMPARISONS

42° SUPERCRITICAL WING GII I VS CURRENT GII

AVERAGE CRUISE WT = 50,000 LBS
S_x = 800 ft^2

MAXIMUM SPECIFIC RANGE - ALTITUDE

MACH NUMBER FOR MAX SPECIFIC RANGE - ALT

ALT ~ FT.

30,000

40,000

MAX S.R. ~ N.M./LB

0.12

0.14

0.16

GII

GII(S)

0.6

0.7

0.8

M FOR MAX S.R.

GII

GII(S)

M.S.

11-19-70
PERFORMANCE COMPARISONS

42° A SUPERCRITICAL WING GII vs CURRENT GII

AVG CRUISE WT = 50,000 LBS
$S_w = 800 \text{ FT}^2$

SPECIFIC RANGE @ MAX CRUISE PWR

MACH NO. @ MAX CRUISE POWER - ALT

ALT ~ FT.

SR $\text{MAX CR PWR N.M./LB}$

M $\text{MAX CR PWR}$
PERFORMANCE COMPARISONS

42° SUPERCRITICAL WING GII VS CURRENT GII

ABSOLUTE CEILING
FOR GII(S)

AVG CRUISE WT = 50,000 LBS
S_w = 800 ft^2

SPECIFIC RANGE @
MAX CONTINUOUS PWR

MACH NO. @ MAX CONTINUOUS POWER

SR_MAX CONT PWR ~ N.M./LB

0.06 0.08 0.10 0.12

0.8 0.9 1.0

RR 511-8 ENGINE

RR 512 ENGINE

ALT ~ FT

30,000 40,000 50,000
RANGE COMPARISON
42° A SUPERCritical wing GII vs CURRENT GII

CLimb TO 43000 FT. & CRUISE TO EMPTY TANKS

3000 M(I TRIP TIME SAVING: 36 MINUTES
RAMP FUEL: 23,300 LBS

GII
GII(S)

GII MAX RANGE @ M = .74
GII(S) " " @ M = .82

RANGE @ MAX CRUISE PWR
GII @ M = .82
GII(S) @ M = .93

11%
HORIZONTAL TAIL INVESTIGATION

OIL FLOW STUDIES, CDL SERIES D WTT

M = 0.85

M = 0.90

boundary layer separation

PROBLEM AREAS NOTED:

1) RAPID HINGE MOMENT CHANGE AT M = 0.85 (Fig. a)

2) FLOW OVER ENTIRE ELEVATOR IS DISTURBED AT MACH = 0.95

STUDY AREAS:

1) DESIGN APEX RULLED BULLET FAIRING FOR JUNCTURE OF HORIZONTAL AND VERTICAL TAIL

2) REDUCE AIRFOIL THICKNESS RATIO AND/OR INCREASE SWEEP \( \theta_c = 7\% \), \( \theta_{LE} = 46^\circ \) FOR M = 0.98 (Fig. b)

3) GO TO FULLY POWERED SYSTEM WITH ALL FLYING TAIL

4) SELECT NEW AIRFOIL ~ POSSIBLY SYMMETRIC WHITCOMB SECTION
EFFECT OF AIRFOIL THICKNESS AND SWEEP ON $M_{CR}$

64, SERIES ~ SYMMETRIC SECTIONS

$M_{CR}$ vs. AIRFOIL THICKNESS RATIO, $t/c$, %

$M_{CR}$ vs. WING LEADING EDGE SWEEP, $\Delta_{LE}$, deg.

$\Delta_{LE} = 45^\circ$

$\Delta_{LE} = 40^\circ$

$\Delta_{LE} = 33.5^\circ$
GULFSTREAM P

HORIZONTAL TAIL CHARACTERISTICS WITH MACH

REFERENCE: CAL Series 7, September 65

$\frac{\delta C_{\text{lev}}}{\delta C_{\text{yaw}}}$

$-5^\circ$
$0^\circ$
$+5^\circ$

$\delta C_{\text{pitch}}$

$\delta C_{\text{yaw}}$

ELEVATOR

PRESSURE COEFFICIENT $C_{p}$

% AT 95.2$

BOLT LINE

32.4
64.8
97.2
129.6

no variation with $\alpha_{\text{yaw}}$
ABSTRACT

The Gulfstream II business jet is a low wing aircraft of moderate sweep featuring a T-tail arrangement and two aft-mounted turbofan engines. The paper outlines aerodynamic development of the configuration and control system, highlighting significant design decisions and aerodynamic characteristics with appropriate experimental data including force, pressure, and flow visualization results. Aerodynamic design considerations included: wing optimization to meet the requirements of high and low speed performance and a pitch-down stall break at all flight conditions while providing adequate fuel volume; nacelle-pylon-wing relationship for optimum drag, engine characteristics, and airplane balance; and an empennage arrangement providing satisfactory stability and control at all conceivable flight conditions. The Gulfstream II configuration provides strong aerodynamic resistance to inadvertent secondary stall entry and more than adequate recovery capability.

THE GULFSTREAM II is a twin-jet swept wing corporate transport designed to provide high speed and long range capability without sacrificing the airport performance, reliability, and other operational advantages of its predecessor, the turboprop Gulfstream I. The design originated when product improvement studies on the Gulfstream I indicated only a new configuration would realize the improvements in performance desired. On the basis of these studies, performance goals of coast to coast range, 0.80 Mach number cruise speed, and airport performance equal to Gulfstream I were established. During preliminary design, the cruise speed requirement was raised to 0.83 Mach number to provide intermediate range route times competitive with airline schedules.

The Gulfstream II, shown in Figs. 1 and 2, features a low wing of moderate sweep, two aft-mounted engines, and a T-tail empennage arrangement. The engines are Rolls-Royce Spey RB 163-25-turbofans rated at 11,400 lb of take-off thrust, giving a minimum thrust to weight ratio of 0.4. Maximum take-off gross weight is 56,000 lb. A fuel capacity of 21,500 gal is sufficient for a theoretical (dry tanks) range of 3400 nautical miles. Take-off and landing performance is illustrated in Fig. 3. The cabin is comparable in size to the DC-3, typically accommodating 10-12 passengers in a corporate interior.

CONFIGURATION ARRANGEMENT

In establishing the aircraft's general arrangement, suggestions from corporate pilots and the lessons and examples of a successful predecessor weighed heavily within the normal performance and geometrical restraints. The general size, fuselage cross-section, and low wing location are examples of "inherited" configuration details, whereas the wing planform and contours reflect the increased performance spectrum.

Preliminary design of the wing was influenced by both cruise and low speed considerations. A wing sweep evaluation indicated a quarter chord sweep limit in the order of 25 deg for acceptable maximum lift capability and good stall characteristics without the cost and complexity of leading edge high lift devices. This degree of sweep appeared to be near optimum for the 0.80 Mach number cruise requirement and satisfactory for the maximum range conditions. The critical performance requirement for the airplane is the long range cruise guarantee which was established as a minimum 0.75 Mach number at 40,000 ft for 3200 nautical miles. This theoretical range is equivalent to New York to Los Angeles against a 90-knot headwind using the National
Business Aircraft Association (NBAA) jet range format. Parametric analysis of this condition indicates an optimum wing loading in the order of 55-60 psf and an optimum sweep somewhat less than 20 deg. Moderate variations in sweep and aspect ratio, however, are not critical. Concurrent with wing sizing, preliminary evaluation of the engine location favored a fuselage mounting which precluded a low stabilizer location. Accordingly, a nose-down pitching break at the stall due to a favorable stabilizer contribution was unlikely, and the aspect ratio of the wing was compromised to minimize wing pitch-up tendency.

The engine location is obviously not an "inherited" characteristic, its selection entailing extensive analysis and design iteration. Aerodynamic analyses and wind tunnel investigations indicated the wing and fuselage mountings offered approximately equal performance potential, although the sensitivity to interference effects appears greater with the wing installation. Design studies revealed considerable problems in achieving a satisfactory compromise of the aerodynamic, structural, and ground clearance requirements of the wing-mounted configuration. These problems were compounded by the large engines and a working environment that includes operation on unswept runways. The advantages of a cleaner wing (particularly with respect to flap geometry), less severe single-engine control requirement, and an improved cabin environment with respect to noise and visibility, which are inherent in an aft engine installation, were decisive when contrasted with the difficulties encountered with the wing installation.

The aft engine location restricts placement of the horizontal tail but the decision to mount the stabilizer at the vertical fin tip derives from many considerations. From an aerodynamic viewpoint, the T-tail arrangement maximizes both the horizontal and vertical tail stability contributions and minimizes empennage and trim drag penalties. Wind tunnel tests indicated undesirable characteristics with a mid tail location, including nonlinear pitching and yawing momen- t variations and a pitch-up at the stall due to early wing wake influence. The effect of tail height at very high angles of attack was not a decisive factor.

CONTROL SYSTEM

The selection of the Gulfstream II control system also involved considerable analysis and design iteration. Customer preference favored retention of the Gulfstream I man-
initiate deflection at 20% of aileron travel to avoid spoiler deflections with trim or autopilot inputs. Pilot feel is again directly from the surface hinge moments and a boost ratio of three was used to provide lateral control forces similar to the Gulfstream I. Lateral trim is obtained with a cable driven tab on the left aileron.

The directional control system is fully powered in normal operation but the mechanical connection to the rudder is similar to the aileron and elevator controls (infinite boost ratio). The directional control actuator is torque limited to prevent excessive rudder deflections at the higher airspeeds. Rudder forces are obtained from a two slope spring with a maximum force of 100 lb and directional trim is accomplished by shifting the feel spring. In manual reversion, due to loss of both hydraulic systems or both engines, the actuator pressure is eliminated and pedal forces reflect both the surface hinge moment and feel spring force. Dutch roll stability augmentation is provided for passenger comfort and minimum pilot effort by means of a yaw damper connected in series to eliminate feedback to the rudder pedals. A damper authority of ±3 deg of rudder travel provides essentially dead beat damping throughout the flight envelope.

CONFIGURATION DEVELOPMENT

The aerodynamic development program consisted of analytical and experimental studies. The wind tunnel program was largely conducted on two models: a 1/15-scale, sting-mounted high speed model, used for seven series of tests in the Cornell Aeronautical Laboratory 8-ft transonic tunnel; and, a 1/10-scale low speed model mounted either conventionally on centerline struts (complete model) or on a reflection plane (half model). The low speed tests covered seven series in the Grumman facility, reflection plane tests to 1/3 full scale Reynolds number at the Cornell Aeronautical Laboratory, and a complete model series to 1/2 full scale Reynolds number at the NASA Ames 12-ft pressure tunnel. In addition to the standard force and moment measurements, these tests provided inlet performance, mass flow influence, control surface hinge moments, stabilizer loads and moments, pressure surveys, and flow visualization for speeds to 1.0 Mach number and angles of attack to 50 deg. The reflection plane tests were somewhat limited in usefulness by difficulties in "mirroring" the stabilizer without fouling but permitted measurement of forces with secondary airflow in the nacelles to simulate mass flow effects, and high angle of attack characteristics without support interference.

The advances in wind tunnel testing during the last decade were found particularly useful in developing the configuration and eliminating the usual trouble spots. The ability to obtain on-line measurements of overall forces and moments, individual strain gage readings, and a large number of local pressures, simultaneously with direct visual and/or film recording of flow representations, greatly reduced the time and "art" required to obtain practical, efficient aerodynamic shapes. The increased flexibility of the tunnel as a development tool permitted improved cooperation with lofting engineers and on-the-spot resolution of internal volume and external shape conflicts such as wheel fairings and wing-fuselage intersection. Further, the use of numerical control lofting and machining techniques permitted compatibility and agreement between the wind tunnel models and the airplane to an unprecedented degree.

WING DESIGN - Primary development effort was devoted to establishing wing geometry. During preliminary configuration sizing it became evident that fuel capacity would be a critical factor in meeting the range guarantee. Also, the conflicting maximum cruise speed requirement was raised to 0.83 Mach number to insure scheduled airline performance at intermediate ranges. Research effort was initiated to develop the airfoil geometry required for maximum sweep benefit from the selected planform, to increase the degree of freedom in selecting thickness and fuel volume. The interference problem at the wing-body juncture was treated by modification of the airfoil shape and thickness over the inner third of the wing span. An inverse camber line modification was calculated using Kuchemann's theory. The restoration of inboard loading and an increase in upper surface velocities to achieve a favorable isobar distribution was accomplished by a combination of incidence, thickness, and thickness distribution. The treated wing provides a relatively large thickness at the root (13%) and the improvement in fuel volume permitted some latitude in selecting outer panel thickness variation.

The basic airfoils for the main area of the wing are similar to those of the A6-A attack aircraft and utilize NASA six series thickness distributions combined with an in-house mean line. The forward camber of these airfoils is magnified by increasing the leading edge radius tangent to the basic upper surface contour, the leading edge radius factor varying from 1.4 at the 1/3 span location to 4.7 at the tip. In developing the wing contours, information derived from the English literature was of invaluable assistance in attaining an efficient configuration in a reasonable time.

High speed wind tunnel tests confirmed the favorable sweep benefits of the treated wing and also demonstrated the insensitivity in upper surface flow development to modifications of lower surface leading edge geometry. The limiting condition in increasing leading edge radius for beneficial low speed characteristics was the deterioration in negative lift buffet boundary due to cusping behind the leading edge. The performance of the configuration was better than expected due in part to a favorable compression tendency ahead of the shock, illustrated by the pressure distribution of Fig. 4. A significant influence of the nacelle on wing loading and shock wave development was also noted. The compression influence of the nacelle has a beneficial drag effect but adversely affects shock-induced separation on the outboard portion of the wing. Also the overlap of the nacelle and wing creates a region of accelerated flow that intensifies with increasing Mach number, increasing the transonic trick tendency. The wing pressures in the vicinity of the nacelle illustrate this acceleration (Fig. 5). It is in-
testing that no separation was observed in this region, the flow changing directly from normal recovery to a trailing edge shock condition.

On the basis of the wind tunnel results, the maximum speed prediction for the aircraft was raised to 0.65 Mach number. A buffet boundary commensurate with this speed capability was attained by incorporating a row of co-rotating vortex generators on the outer wing panel. In designing the vortex generators, a paper by Pearcey (1)* permitted establishment of an optimum configuration on the initial attempt. The influence of the vortex generators on the buffet onset boundary is shown in Figs. 6 and 7. Both the vortex generators and a boundary layer fence contoured to the upper surface streamlines manifest no measurable cruise drag penalty.

In developing the wing contours, cognizance was taken of the aircraft's low speed requirements by tailoring the leading edge radius to preclude leading edge separation and by consideration of local loading. The maximum lift capability of the wing was not critical due to the low wing loading (large wing area required for long range cruise and fuel volume requirements), the high thrust loading, and advances in braking capability. The high lift configuration, which consists of a one piece, single-slotted Fowler flap of

*Numbers in parentheses designate References at end of paper.

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Fig. 4 - Wing pressures (outboard)

W. Sta 314 \( \frac{76}{2} \) 
\( \alpha = 2^\circ \) 
(T.E. Sep at 0.95 M)

Fig. 5 - Wing pressures (inboard)

Nacelle Off

W. STA 75 \( \alpha = 2^\circ \)

Nacelle On

N. Sta 90 M

0.85 M

0.80 M

0.75 M

20 40 60 80 100

% Chord

(P/H)

0.7

0.6

0.5

0.4

0.3

0.2

0.1

0

\( M \)

50000 lbs GW

40000 Ft Alt

Vortex Gen On

n = G

1.6

1.4

1.2

1.0

70 78 80 85 90

Mach No. - M

Fig. 6 - Effect of vortex generators on buffet boundary

Fig. 7 - Effect of vortex generators on buffet boundary

Fig. 8A - Wing stall progression - \( \alpha = 15^\circ \deg \)
NACELLE DESIGN - The sensitivity of nacelle drag penalty to location and orientation was established early in the development program, but difficulty in minimizing nacelle interference arose from conflicts with nonaerodynamic factors. An overlap of nacelle and wing, for example, was unavoidable within the geometrical and weight and balance restraints of the configuration, yielding a strong sensitivity to fore and aft location. Early configuration studies called for an off-the-shelf engine pod with integral cascade-type thrust reversers, but modifications reducing the inlet length and reshaping the inlet cowl for the Gulfstream II application were dictated by drag considerations. When the cascade-type reversers were eliminated, due to cruise drag and net thrust penalties, in favor of target type reversers, full design freedom for the nacelle shape was realized.

Reduction of the wing-nacelle interference to a practical minimum involved a most aft nacelle location within the limits of balance and structural considerations, a minimum inlet length consistent with crosswind requirements, and optimization of nacelle incidence. The influence of nacelle pitch orientation derives from both inlet alignment with the local flow conditions and modification of the flow channel shape between the nacelle and wing. The optimum drag orientation also provides full pressure recovery at the engine compressor face at all flight conditions. In the developed configuration, the sensitivity to further aft movement has been reduced to an insignificant level and vertical location is not a drag consideration within the limits investigated.

An additional interference region is the channel formed by the nacelle-pylon-fuselage intersections. The engine mounting geometry and engine-pylon interface precluded symmetry in the pylon-nacelle relationship, aggravating the pylon lower surface channel geometry. Significant relief, particularly at high Mach numbers, was achieved by rolling the engine and pod relative to the fuselage, opening the channel, and eliminating acute corners as shown in Fig. 9. In optimizing the nacelle geometry, careful attention to small geometry details was found necessary to minimize interference or compressibility effects and avoid separation. The relationship between cowl curvature and pylon leading edge shape and location, or the establishment of the pylon trailing edge geometry, are examples of fruitful areas of refinement. The resulting nacelle drag penalty at cruise conditions is shown in Fig. 10 and includes an adverse nacelle influence on span loading. Note that a beneficial interference effect is introduced at the higher Mach numbers.

The disadvantages associated with an overwing nacelle location have been stressed, but there are also benefits to be derived. Because of its relationship to a rather large turning vane, the inlet operates at low angles of attack with no measurable pressure recovery penalty throughout the normal flight envelope. Also, the problem of wing wake ingestion at stall, buffet onset or with wing spoilers extended is avoided and the nacelle wake influence on the tail at very high angles of attack is considerably minimized.

Detailed wind tunnel studies were made of the static and dynamic compressor face pressure characteristics over a wide range of angle of attack, sideslip, and speed. Negligible distortions were noted up to sideslip angles of 15 deg and, the crosswind investigation, which indicates the lee engine is critical, justifies clearance for 40-knot crosswinds.

Fig. 8B - Wing stall progression - $\alpha = 18$ deg

Fig. 8C - Wing stall progression - $\alpha = 23$ deg

Fig. 9 - Nacelle roll effect

Fig. 10 - Nacelle drag increment
Relatively large static distortions coupled with a high level of dynamic fluctuations were measured, however, at angles of attack beyond wing stall, particularly at maximum engine mass flow. Peak to peak total pressure fluctuations in the order of 0% were noted for take-off power conditions as compared to a maximum of 3% at idle power. Smoke studies were useful in confirming the wing separation-inlet ingestion relationship and the timing and intensity of the distortions were modified by changes in wing stalling behavior and maximizing nacelle vertical location. The static distortions at any condition are well within the engine manufacturers specification but the adverse influence of the superimposed dynamics on engine stall margin could not be predicted. Rolls-Royce interest and assistance on the problem included tests in both its sea level bed and altitude chamber to ascertain the effect of combining dynamics with known static distortion levels. The results indicate a reduction in engine stall margin but stall free operation of the engine is anticipated on the basis of these tests even during stall penetrations to high angles of attack.

DEEP STALL. - A detailed analysis of the contributing factors and physics of the deep stall problem is unnecessary and redundant considering the attention it has received in the literature (Refs. 2 and 3 are excellent and thorough examples). The worldwide deep stall alarm was sounded during the early development studies of the Gulfstream II. High angle of attack wind tunnel tests and analog computer motion studies, which were accordingly incorporated into the development program, provided insight into the basic mechanisms and an appreciation of the influence of configuration variables. The candid nature of industry-wide communication on the deep stall also contributed significantly to its understanding and the ability to evaluate the adequacy and safety of the Gulfstream II design.

The high angle of attack investigations on the Gulfstream II indicate:

1. Stable trim conditions exist up to 45 deg angle of attack.
2. The elevator deflection required to trim to the primary stall at most forward center of gravity is sufficient to trim a deep stall at the aft center of gravity.
3. Recovery from deep stall is immediate upon forward stick motion, that is, more than adequate nose-down elevator control is available (Figs. 11 and 12).

In addition to adequate control effectiveness at all angles of attack, the control column is mechanically connected to the elevator such that no auxiliary devices are required to insure airplane response. The acceptability of the Gulfstream II high angle of attack characteristics and the absence of a deep stall influence on configuration sizing and arrangement is attributed to the mitigating influence of the nacelle-wing overlap on nacelle contribution. Configuration buildup studies reveal the adverse nacelle influence on tail pitching moment contribution above 30 deg angle of attack (Fig. 13) is not unduly severe and no appreciable effect on elevator or stabilizer effectiveness is evidenced (Fig. 14). Recoverability of the aircraft from any stall condition is a prerequisite to configuration acceptability but a strong resistance to deep stall entry and the attainment of good primary stall behavior are equally important. A design require-
ment on Grumman aircraft is a nose-down moment break at the stall and the configuration development efforts devoted to this end were described earlier. As noted, the low speed wind tunnel results indicate an increase in stability at the stall and a margin of 6-8 deg angle of attack between initial stall and tip separation. The analog studies using these data indicate deep stall entries for the Gulfstream II will require near-maximum attainable control deflections or elevator deflections well in excess of those for primary stall coupled with high approach rates or strong gusts.

During the course of the high angle of attack studies, some observations and items of general interest were noted. A large variation in Reynolds number (1 to 7 million) provided anticipated effects on lift and pitching moment varia-
tions in the vicinity of primary stall but virtually no effect at angles of attack above 28 deg. Mach number variations from 0.13 to 0.60 also had a pronounced influence on primary stall angle of attack without significantly altering the secondary stall behavior. Reflection plane tests to high angles of attack indicated slightly less tail contribution to sta-
bility below wing stall, attributed to difficulties in obtaining proper reflection at an appreciable distance from the support point without fouling, but equivalent to better tail contribution at the higher angles of attack. It is not known whether this is due to the absence of support interference or alteration of fuselage vortex influence. The deterioration in elevator or stabilizer effectiveness with increasing angle of attack was also somewhat less for the reflection plane model suggesting unaccounted, adverse support effects may remain in the complete model results. A complete model evaluation of nose length showed no change in tail contribution between the standard fuselage and cutting back to a hemispherical nose ahead of the wing body juncture.

Recovery studies on the analog computer indicated recovery can be accomplished under all conditions (and to the limits of a large tolerance band on the aerodynamic data) by returning the control column to its original trim position. Minimum altitude loss during recovery (in the order of 1000 ft from a fully stabilized deep stall trim condition) is achieved by restraining nose over pitch rate to a reasonable level. The addition of power is beneficial as it adds a large force vector normal to the flight path, assisting the pullout.

HANDLING QUALITIES - Excellence in handling qualities is a Grumman reputation that is fully maintained by the Gulfstream II design. Handling qualities specifications are currently the subject of much research, and evaluation of the design during its development involved examination of a number of existing and proposed criteria in addition to the usual in-house standards. The greatest influence of handling qualities during configuration development arose from lateral-directional considerations, particularly the dutch roll mode. The principal design parameters influencing the dutch roll are the static lateral stability (dihedral effect), damping in yaw and roll, and product of inertia (I_{xx}).

Increases in vertical tail area and tail arm were incorporated during development to increase yaw damping and attain the desired level of directional stability. The aft en-
gine, T-tail arrangement incurs an adverse principal axis inclination but cognizance of this factor early in the program permitted significant reduction in the product of inertia as the design evolved. In developing the configuration, restriction of the geometric dihedral was attempted to offset the increase in dihedral effect with increasing lift, common to swept wing aircraft. Limitations imposed by the fuel system, and by flap trailing edge clearance in an extreme landing situation, restricted the geometric dihedral to a minimum of 3 deg. Wing bending in normal flight increases the lateral stability equivalent to an additional 1.5 deg of wing dihedral. Stability calculations with the estimated characteristics indicate acceptable dutch roll damping throughout the flight envelope but less than satisfactory levels at very high altitudes and possibly objectionable work-load in approach and landing. Stability augmentation, in the form of a series yaw damper, was incorporated into the configuration to insure the desired absence of extraneous pilot effort during approach and landing as well as satisfactory passenger comfort in high altitude turbulence. Loss of the yaw damper at higher altitudes is not critical.

Configuration criteria based on static longitudinal stability and control considerations also provide satisfactory longitudinal handling qualities under all flight conditions. In terms of dynamic stability, damping of the short period and phugoid oscillations satisfy the appropriate military specification. New criteria suggested for longitudinal handling qualities, taking into account aircraft response and controllability, include Birle's Control Anticipation Parameter (CAP) (4) and Shomber and Genten's bulls-eye approach (5). The Gulfstream II CAP ranges 20-40 deg/sec/ft, indicating satisfactory precision control capability, particularly in the approach and landing conditions. On the basis of the Shomber and Genten approach, satisfactory precision control is predicted for cruise conditions up to approximately 30,000 ft and acceptable characteristics at the higher altitudes. For approach and landing, the characteristics are centered in the appropriate bulls-eye. Statically, the wind tunnel data evidence linear stability and control characteristics to stall or buffet onset conditions while flying quality calculations indicate speed stability levels well within FAA maximum and minimum requirements and satisfactory maneuvering gradients without recourse to springs or bobweights.

FLIGHT RESULTS

Flight testing is ideally a confirmation process but almost always includes a share of the configuration development effort. The Gulfstream II flight testing to date has been very encouraging, showing close agreement with most predictions and generally better performance than estimated, but changes in the configuration have been made in the flying qualities area to improve lateral control and reduce trim changes due to power and flaps. Revisions were also required with respect to stall characteristics and to eliminate an objectionable buffet at full flap deflection. The flap buffet
was mild at approach flaps but severe with landing flaps. Flight tuft studies (Fig. 15A) confirmed the suspected separation in the vicinity of the flap tracks as well as fully attached flow through the slot. A turning vane configuration developed earlier on the low speed tunnel model was incorporated, reducing the separation and associated buffet to an insignificant level (Fig. 15B).

Stability levels closely correspond to wind tunnel measurements and the predicted dutch roll behavior at high altitudes has been confirmed as acceptable (yaw damper off). For the approach and landing conditions, damping appears better than predicted and is considered satisfactory with the damper inoperative. Buffet boundary determination indicates buffet onset lift coefficients slightly higher than estimated, confirming the generous buffet margins of the design.

LATERAL CONTROL - The lateral control effectiveness was suspected to be less than optimum prior to flight but satisfied existing and proposed criteria. In flight evaluation, it was immediately evident that higher roll rates and lower force gradients than suggested by these criteria are considered necessary for satisfactory "jet" performance and control harmony. The principal objection to roll performance related to sensitivity near neutral and a nonlinear variation with wheel deflection; maximum roll rate capability was satisfactory. The increased sensitivity through neutral was achieved by revision of the spoiler-aileron mixing, including the use of spoilers out of neutral, while the desired force levels were attained by increasing aileron boost ratio to 5.0. The measured roll performance for the revised configuration, shown in Fig. 16, is considered optimum for the approach configuration and satisfactory at all other flight conditions.

TRIM CHANGES - During preliminary design of the Gulfstream II, engine exhaust influence on horizontal tail flow was estimated as relatively minor and jet flow simulation was not included in the wind tunnel program. The location of the engine pod introduces a sizable direct thrust moment, however, and the engine nozzle was designed to orient the thrust vector closer to the center of gravity and eliminate trim changes with power. Measurement of engine mass flow influence during the wind tunnel program indicated changes in wing loading and a small nose-up moment but the magnitude of the change did not warrant revision of the nozzle design. Inflight measurements, however, indicated a significant nose-up moment with power application. A limited pressure survey confirmed the wind tunnel measurements for the wing but suggests flow field changes at the tail are larger than estimated. It was decided to eliminate the trim changes by reorientation of the thrust vector, the revision being accomplished by redesign of nacelle and tail pipe transition components without change to the thrust reverser assembly. With the modified configuration, stick-free applications of power yield insignificant changes in attitude.

Another trim change considered during the design was that associated with flap retraction or extension. The gearing of the stabilizer to the flap drive, discussed in the control system development, was mechanically accomplished by means of a simple, direct linkage. Design conditions for the gearing were the minimum drag stabilizer position (zero incidence) with the flaps retracted and -4deg incidence (appropriate with desired take-off performance) at the take-off flap setting (20deg). This gearing yielded -5.5deg of incidence with the 40deg landing flap and permitted trim tab sizing on the basis of clean requirements. Flap trim change estimates for this gearing were not completely satisfactory...
in that push forces were indicated for flap extension between clean and approach (zero to 20 deg). The forces were considered acceptable, however, in that they satisfied the FAA regulations and in view of the time associated with the flap extension (15 sec). Estimated changes for extension from approach to landing flaps were small and in the pull direction.

Flight testing confirmed the order of magnitude and direction of the flap trim changes but alleviation of the trim change occurring with flap retraction after take-off was recommended. The flight results also showed the desired rotation and take-off performance could be achieved with less incidence at the take-off flap setting. As the undesirable portion of the trim change occurred between zero and 10 deg of flap and was very satisfactory over the rest of the range, the desired effect was accomplished by introducing a dwell range in the flap-stabilizer gearing relationship. The dwell unit, designed by AirResearch, idles the stabilizer during 28% of the drive travel, without hysteresis, as shown in the gearing comparison of Fig. 17. The revised gearing provides small flap trim changes under all conditions and sufficient stabilizer incidence at take-off and landing to satisfy trimmability and take-off performance requirements.

STALL CHARACTERISTICS - The stall characteristics of the Gulfstream II are best described as docile: a very mild, easily controllable lateral twitch or wallow simultaneous with buffet onset, the buffet intensity increasing with increasing penetration. No g break is experienced and both lateral and longitudinal control remain excellent. In-flight tuft studies and the longitudinal control characteristics evidence close correlation with tunnel results (Fig. 18) but the increased stability evidenced at stall initiation is not discerned by the pilot. The absence of the desired g break is associated with the gradual spread of the stall on the wing and the corresponding lack of downwash change at the tail. The stall characteristics are satisfactory in themselves but do not preclude stall penetrations to the point of secondary stall pitchup. Inboard leading edge tripper strips, to promote a more widespread stall break, were investigated briefly but caused only pre-stall buffet or no discernible change. Removal of the wing fence was evaluated but elimination of the stall initiation anchor point yielded an objectionable roll off. Rather than pursue a lengthy flight test research effort, and in view of the excellent primary stall behavior, it was decided to mechanically limit the extent of stall penetration.

PERFORMANCE - On the basis of the testing accomplished to date, the performance of the airplane is better than estimated and the equal of our hopes. The estimated specific range has been exceeded by approximately 7% throughout the speed, weight, and altitude range of the aircraft. A representative specific range - Mach number curve, presented as Fig. 19, indicates the guaranteed New York-Los Angeles capability (90 knot headwinds, NBAA jet range format) can be achieved at 0.80 Mach number. The maximum speed capability is well above the guaranteed 0.83 Mach number at 30,000 ft as well as the later 0.85 Mach number prediction. The maximum cruise Mach number at 30,000 ft is in excess of 0.86 and a heavyweight 0.86 Mach number capability is indicated for altitudes in excess of 40,000 ft. The expected single and twin engine climb performance has been demonstrated repeatedly. Twin engine climb at near maximum weight to 40,000 ft has been accomplished in 15 minutes from brake release with a recorded rate of climb at 40,000 ft in excess of 1500 fpm. Preliminary take-off and landing checks indicate the estimated airport performance will also be achieved.

![Fig. 17 - Flap-stabilizer gearing](image)

![Fig. 18 - Control characteristics in stalls](image)

![Fig. 19 - Specific range](image)
REFERENCES


GULFSTREAM B SUPERCRITICAL WINGS
ESTIMATED TAKEOFF PERFORMANCE
SEA LEVEL — STANDARD DAY

CL_{MAX} = 1.5
CL_{MAX} = 1.75
CL_{MAX} = 2.0

TOTAL TAKEOFF DISTANCE TO 35 FOOT OBSTACLE
4600
4200
3800
3400
3000
2600
2200

TAKEOFF GROSS WEIGHT - 1000 LB
48
52
56
60
64
68
# G.A.C. NST DEVELOPMENT PLAN

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
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<tr>
<td>No. Amer. FB-1 (E)</td>
<td>△</td>
<td>*</td>
<td>?</td>
<td>.</td>
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<td></td>
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<tr>
<td>No. Amer. FB-2 (H)</td>
<td>✗</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td>NASA T-2C</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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<tr>
<td>No. Amer. T-2C (366)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Inert 3/4 (SCU, not related to NST)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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</table>

| PROTO. DEVELOP. | | | | | | | |
| TEST AIRCRAFT AERO. | PHASE A | | | | | | |
| EFFECT | | | | | | | |
| - WEITCOMS CONCEPTS | | | | | | | |
| - INDUSTRY COMPETITION | | | | | | | |
| >(3) | | | | | | | |

| LEGEND | RELEASE RFP | PROPOSAL SUBMITTED | CONTRACT AWARDED | FUSEL TESTS | FIRST FLIGHT | CONTRACT COMPLETED | |
|--------|-------------|---------------------|------------------|-------------|--------------|-------------------|
### NASA/G.II NST Weight and Balance Summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Demo</th>
<th>Prod.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical G.II Production Oper. Weight</td>
<td>35600</td>
<td>lbs.</td>
</tr>
<tr>
<td>Remove: Non-essential Furnishing in Demo</td>
<td>-804</td>
<td>0</td>
</tr>
<tr>
<td>Remove: G.II Wing and contained ctrls, etc.</td>
<td>-7300</td>
<td>-7300</td>
</tr>
<tr>
<td>Add: Whitcomb SCW 770 sq. ft. ref. area and contained ctrls, etc. (Note: Both wings assume prod. design, demo lacks L.E. slats)</td>
<td>+7550</td>
<td>+7970</td>
</tr>
<tr>
<td>Refined fwd. fus. lines, radome and &quot;coke&quot;</td>
<td>+558</td>
<td>+338</td>
</tr>
<tr>
<td>Move aft section, aft of sta. 456, aft 54&quot;, including engines and tails and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Add 54&quot; structural &quot;slug&quot; -</td>
<td>+500</td>
<td>+450</td>
</tr>
<tr>
<td>- Bending, torsion and shear material for added tail length.</td>
<td>+126</td>
<td>+96</td>
</tr>
<tr>
<td>- Controls, wires, ducting increase length</td>
<td>+20</td>
<td>+20</td>
</tr>
<tr>
<td>Add - Air Condit. and pressurization revisions for increased cabin length and $V_L$</td>
<td>0</td>
<td>+36</td>
</tr>
<tr>
<td>- Soundproofing, trim, floor cover, etc. for longer cabin; add (2) seats.</td>
<td>+190</td>
<td>+240</td>
</tr>
<tr>
<td>Add - Fin L.E. Sweep $%$ change and other misc. minor revisions to A/C.</td>
<td>+50</td>
<td>+40</td>
</tr>
<tr>
<td>Unknowns</td>
<td>+310</td>
<td>+310</td>
</tr>
<tr>
<td>Operating Weight; incl. (3) crew</td>
<td>36800</td>
<td>37800</td>
</tr>
<tr>
<td>Passengers and Baggage (12)</td>
<td>0</td>
<td>2400</td>
</tr>
<tr>
<td>Zero Fuel Gross Weight</td>
<td>36800</td>
<td>40200</td>
</tr>
<tr>
<td>Fuel - Usable - Wings Box Beam (Est. Max)</td>
<td>22200</td>
<td>20500</td>
</tr>
<tr>
<td>- Aft Lower Fuselage (Est)</td>
<td>1800</td>
<td>1800</td>
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<tr>
<td>- Wing L.E. Glove (Max 2000)</td>
<td>1700</td>
<td>0</td>
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<tr>
<td>Ramp Weight</td>
<td>62500</td>
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#### Maximum Fuel Volume Summary

<table>
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<tr>
<th>Description</th>
<th>Volume</th>
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<tr>
<td>Wing Box Beam</td>
<td>22200</td>
</tr>
<tr>
<td>Wing Leading</td>
<td></td>
</tr>
<tr>
<td>Edge Glove</td>
<td>2000</td>
</tr>
<tr>
<td>Aft Low. Fus.</td>
<td>1800</td>
</tr>
<tr>
<td>Total</td>
<td>26000</td>
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</tbody>
</table>
Grumman GII 62,500 Pound Version
Allowable Gross Weight vs. C.G. Envelope

Note: Weights & C.G.'s for Max. Engines.
May vary Engines.
Add 2,500 lb and Max T.O. C.G.
Aft 0.6% and Oper. C.G.
Aft 1.3%.

Max. Zero Fuel Weight

(12) Passengers & Baggage
Operating Weight - Prod. • Demo

Center of Gravity ~ % M.A.C.
(L.E., M.A.C. = 426.5; M.A.C. = 144")
## Performance Comparison Summary

### 42° A Supercritical Wing GII vs Current GII

<table>
<thead>
<tr>
<th></th>
<th>GII</th>
<th>GII(s)</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{drag~rise}$</td>
<td>.80</td>
<td>.95</td>
<td>$\Delta M = .15$ INCREASE</td>
</tr>
<tr>
<td>$M_{max}$</td>
<td>.87 @ 30,000 ft</td>
<td>.97</td>
<td>$\Delta M = .10$ INCR</td>
</tr>
<tr>
<td></td>
<td>.825 @ 43,000 ft</td>
<td>.95</td>
<td>$=.125$ &quot;</td>
</tr>
<tr>
<td>Max. Spec. Range ~ n.mi/lb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 43,000 ft.</td>
<td>.146</td>
<td>.162</td>
<td>11% INCR</td>
</tr>
<tr>
<td>- Alt. For Best Cruise</td>
<td>.15</td>
<td>.161</td>
<td>7% INCR</td>
</tr>
<tr>
<td>@ 40,000 ft</td>
<td>@ 44,000 ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M_{cruise}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 43,000 ft.</td>
<td>.73</td>
<td>.82</td>
<td>$\Delta M = .09$ INCR</td>
</tr>
<tr>
<td>- Alt., Best CR</td>
<td>.72</td>
<td>.84</td>
<td>$=.12$ &quot;</td>
</tr>
<tr>
<td>3000 n.mi Trip Time</td>
<td></td>
<td></td>
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<tr>
<td>- 43,000 ft.</td>
<td>7 hrs 5 min</td>
<td>6 hrs 23 min</td>
<td>42 min or 10% DECREASE</td>
</tr>
<tr>
<td>- Alt., Best CR</td>
<td>7 hrs 16 min</td>
<td>6 hrs 14 min</td>
<td>60 min or 14% DECR</td>
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