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HSCT

HIGH LIFT SYSTEM AERODYNAMIC REQUIREMENTS

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INTRODUCTION

Low speed aerodynamic performance has been identified as critical to the successful development of an HSCT. The airplane must takeoff and land at sufficient number of existing or projected airports to be economically viable. At the same time, community noise must be acceptable.

Improvements in cruise drag, engine fuel consumption, and structural weight tend to decrease the wing size and thrust required of engines. Decreasing wing size increases the requirements for effective and efficient low speed characteristics. Current design concepts have already been compromised away from better cruise wings, like arrow wings, for low speed performance. Flap systems have been added to achieve better lift-to-drag ratios for climb and approach and for lower pitch attitudes for liftoff and touchdown.

Research to achieve improvements in low speed aerodynamics needs to be focused on areas most likely and have the largest effect on the wing and engine sizing process. It would be desirable to provide enough lift to avoid sizing the airplane for field performance and to still meet the noise requirements. A more economically viable airplane would result if we can accomplish improvements in the high lift system. Some of the "compromises" to the cruise configuration could be returned. Some of the gain will require regulatory changes allowing innovative flaps and flap control systems.

Current design activities tend to be centered on double delta wings, trailing edge-mounted nacelles, and aft tail for trim and control. A "snap-shot" of the low speed strengths and weaknesses for this kind of a configuration will be examined. The airworthiness standards developed in 1971 for the USSST will be the basis for performance requirements for an airplane that will not be critical to the airplane wing and engine size.

Where should research for improved low speed performance be focused?

- **A snap-shot for:**
  - * **One particular study airplane**
  - * **Wind tunnel characteristics for a similar configuration**
  - * **A proposed set of airworthiness standards**
- **A look at:**
  - * **Lift adequate for field performance and speed margins**
  - * **Drag required for climb gradient requirements**
  - * **Sensitivity of noise to drag improvements**

FIGURE 1

SIZING FOR CRUISE PERFORMANCE

Ideally, an airplane's wing area and engine size is selected by cruise mission performance requirements without any penalties to give acceptable takeoff and landing performance. To find out what kind of lift and drag characteristics are required to do this, the climb, cruise, and descent performance is calculated for a range of wing areas and engine sizes similar to the illistration. Limitations due to fuel capacity for the class of wings and fuselages being studied can be indicated as limitations as can off-design performance requirements like a minimum rate of climb. The sized configuration would be the minimum wing area and engine size that satisfied all these conditions. Required low speed performance can be added next.

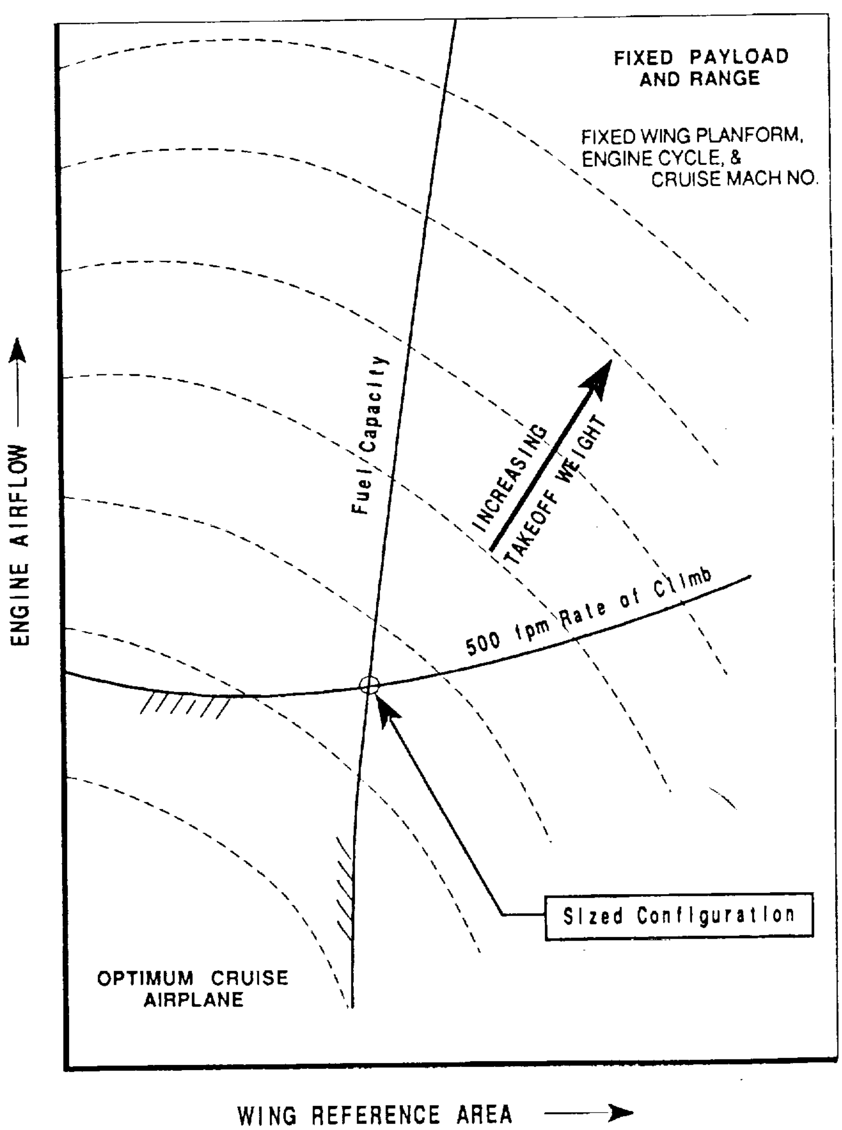


FIGURE 2

<u>LOW SPEED LIFT REQUIRED</u>

The limit of acceptable low speed performance is usually defined for the maximum take off gross weight and the maximum landing weight. The design takeoff field length is related to the airports that are expected to be used. The approach speed is the common parameter for landing and must be considered safe, acceptable to the flight crew, and not require excessive stopping distances even under adverse conditions. Current studies use 11,000 feet for the FAR takeoff field length and 155 knots for approach speed.

For the sized airplane wing area and engine thrust, liftoff and approach lift coefficients can then be calculated that give the design low speed performance. Locus of lines of constant field length and approach speed can then be calculated using these selected lift coefficients as shown for the cruise-defined thumbprint. The values of lift coefficient shown will next be used as starting points to describe related levels of lift that must also be achievable for satisfactory low speed performance.

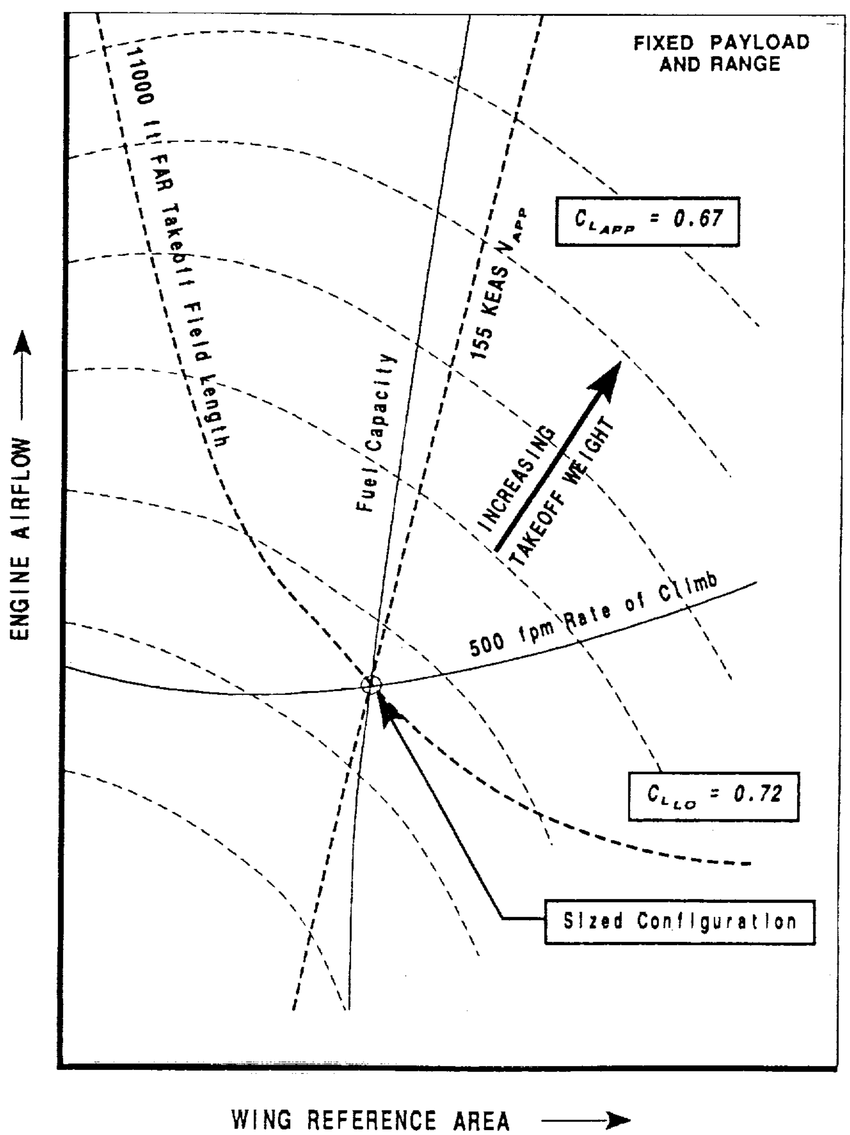


FIGURE 3

LOW SPEED MODEL

The lift and drag needed to give the required takeoff and landing performance will be compared against the characteristics of a low speed wind tunnel model typical of recent configuration studies. The high lift system consists of vortex flaps with vortex fences at the wing apex and unslotted trailing edge flaps. Suppression of leading edge separation was an objective for good climb and approach performance and vortex amplification was used for liftoff and touchdown configurations.

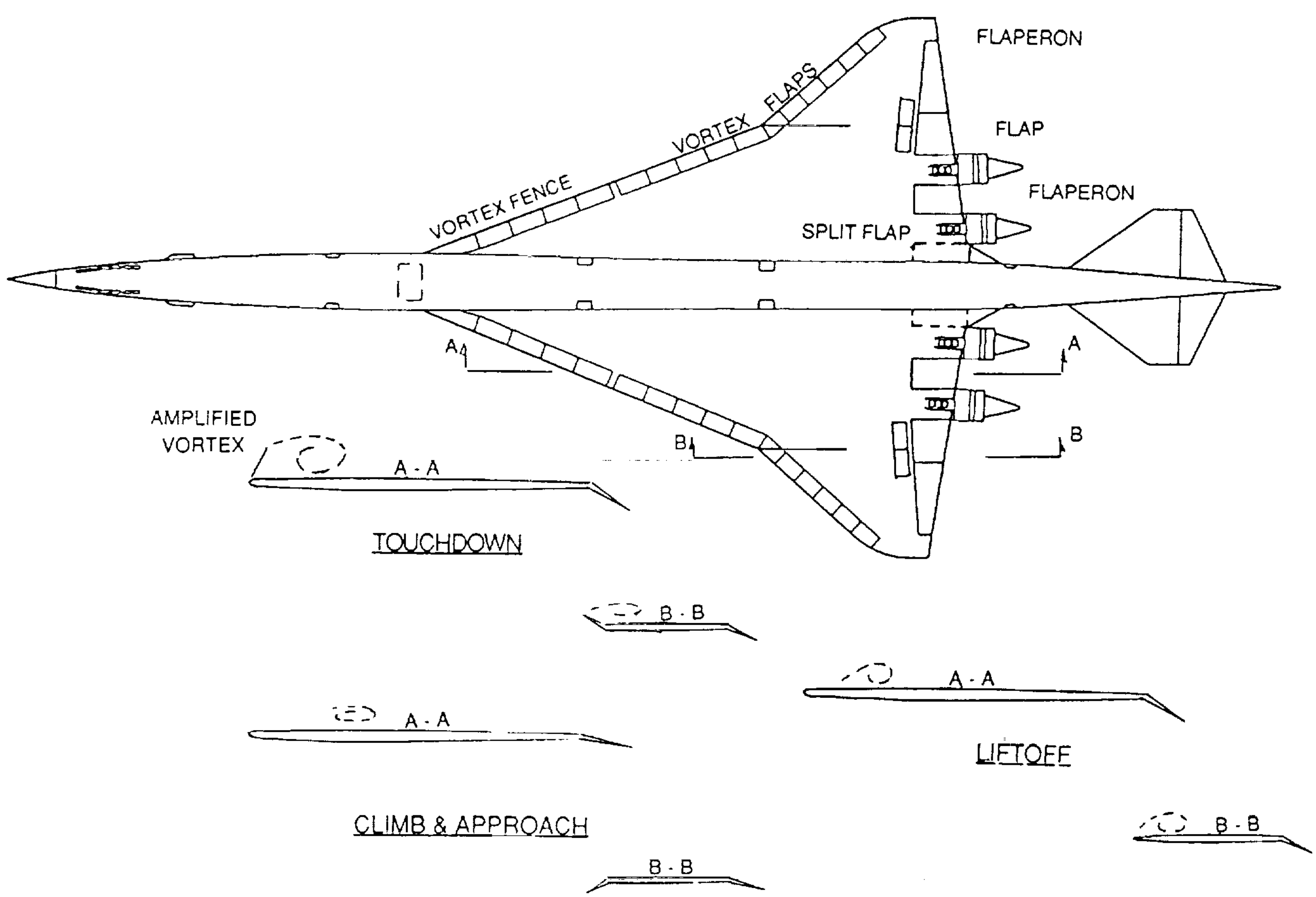


FIGURE 4

HIGH LIFT SYSTEM UTILIZATION

Currently certified airplanes maintain a fixed flap position through takeoff ground roll, liftoff, climb and acceleration until the landing gear is retracted. Similarly, the flap is fixed during landing final approach and is not changed until after touchdown. This convention in operating procedure is required by the Federal Air Regulations (FARs). Automatic procedures that move the flaps in ways that make changes in flap position "invisible" to the crew with equivalent safety need to be made acceptable to the rules when gains in performance can be made. Flaps that reposition themselves in response to angle of attack, speed, altitude, etc. are referred to as "programmed flaps". With them, liftoff and touchdown lift could be increased without necessarily reducing the lift-to-drag ratio during climb and approach. Better climb gradients and lower noise could then be achieved.

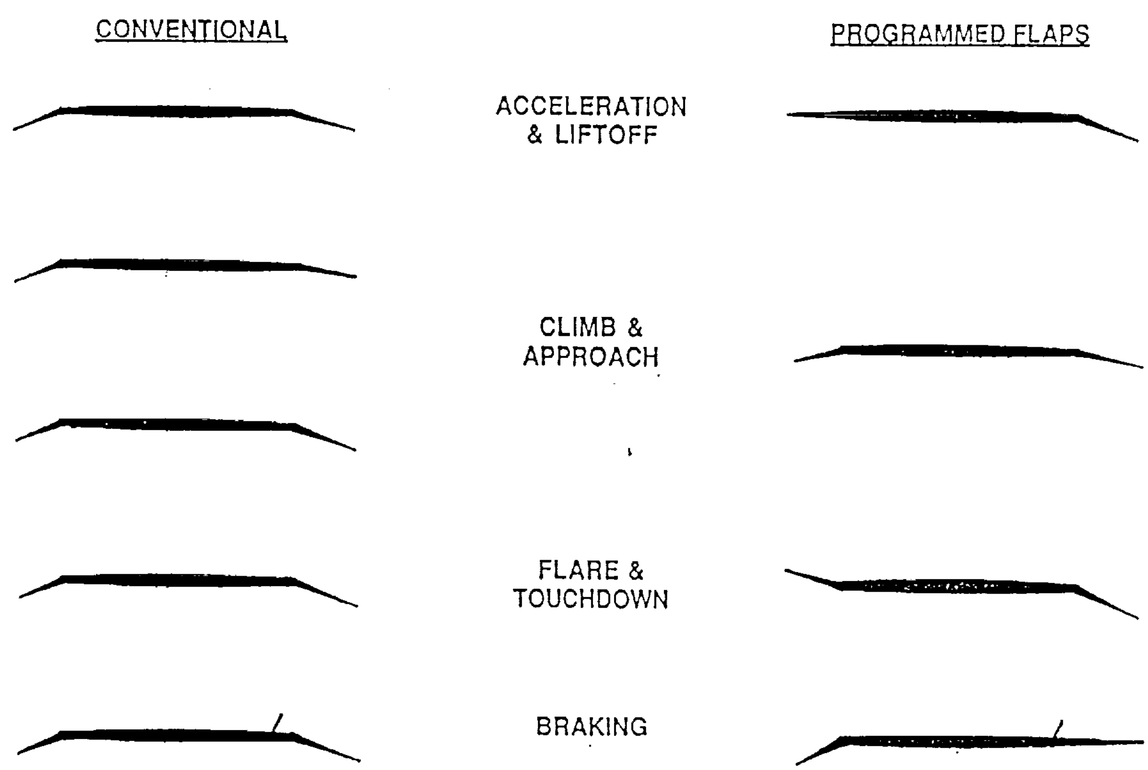


FIGURE 5

LIFT REQUIREMENTS

During the late 1960's and early '70's, a lot of effort was made to define the airworthiness standards for the USSST program prior to its cancelation. The results were the Tentative Airworthiness Standards for Supersonic Transport (1971). These proposed rules recognized, among other things, the significant differences in performance and handling characteristics expected with low aspect ratio wings and high thrust levels.

These proposed rules, along with the Concorde Special Conditions, will have to be reviewed by the industry and further developed to be consistent with projected new technology.

For this study, the TASST's as they existed in 1971 will be used to define and develop the required low speed performance criteria that would be needed in order to have no direct impact on the cruise-sized airplane.

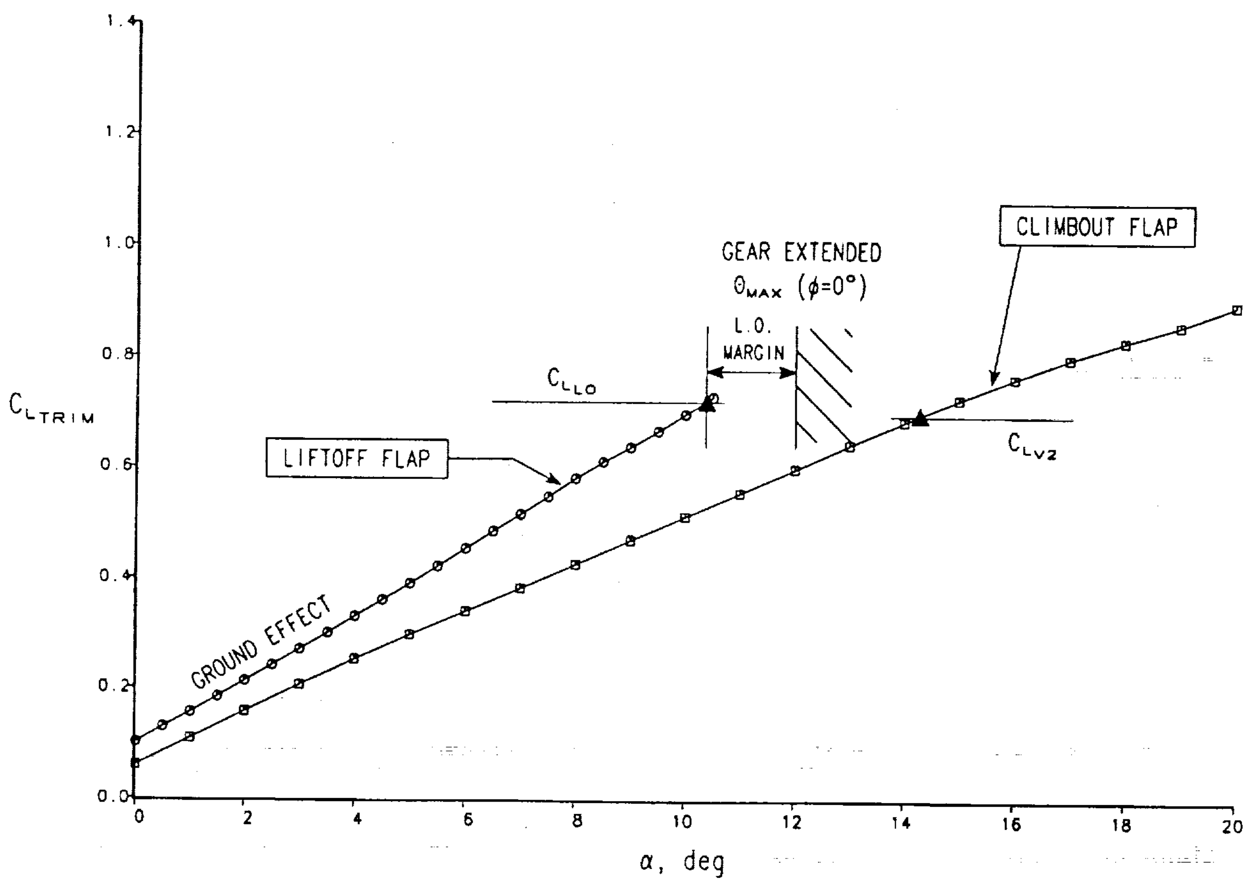
TENTATIVE AIRWORTHINESS STANDARDS FOR SUPERSONIC TRANSPORT (TASST) (1971)

CONDITION	SPEED	REQUIREMENT
Liftoff	V_{lof}	FAR 25.104(b) ....must not require pitch or roll attitudes that may result in unwanted contact of the airplane with the ground. [V_{mu} requirements deleted but other abuse conditions added]
Touchdown	V_{td}	
Takeoff Climb	V_2	FAR 25.104(a) ....the selected speeds must provide adequate and defined margins above the minimum demonstrated speeds..... $V_2 > 1.15\,V_{min}$ FAR 25.107(b)(1); $V_{app} > 1.23\,V_{min}$ { no specific TASST requirement but this value was being used in 1971 }
Approach	V_{app}	
Zero Rate of Climb	V_{zrc}	FAR 25.107(b) ...Speed V2 ...may not be less than: (3) $1.125\,V_{zrc}$ ...
Minimum Performance Reference Speed	V_{min}	FAR 25.103(b) ....the applicant shall define, for each appropriate configuration, a minimum demonstrated flight speed V_{min} ......

FIGURE 6

TAKEOFF LIFT - ATTITUDE LIMITED

Assuming that the wind-tunnel data shown represents the study airplane's capability for lift, the pitch attitude margin to aft-body contact for the liftoff lift coefficient is shown. For maximum takeoff gross weight, a small acceleration occurs during climb to 35 feet (V2). A feature of the assumed programmed flap system is that the angle of attack would have to be increased after liftoff to accommodate the flap that gives better L/D for climb.

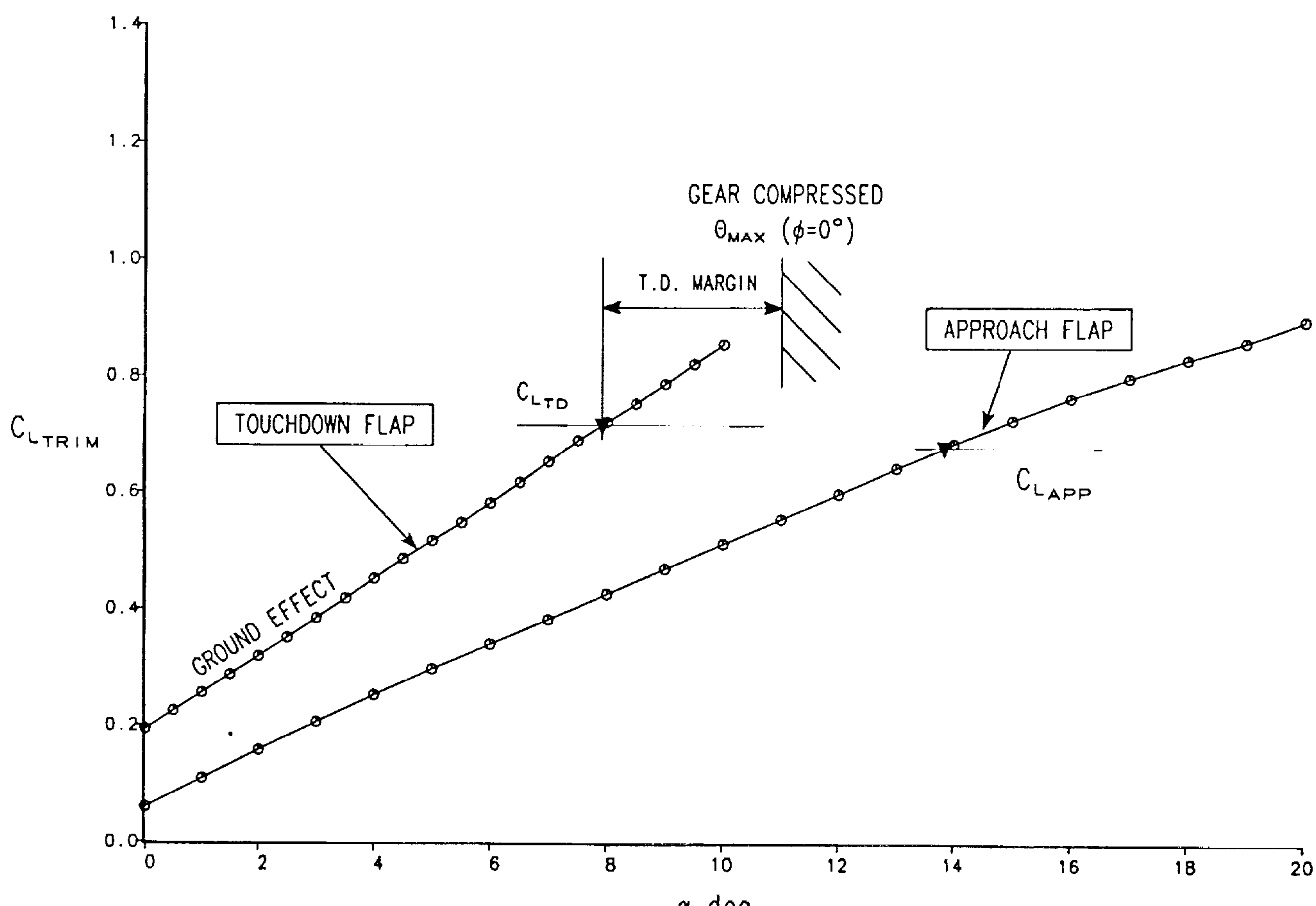


LIFT - LOW REYNOLDS NUMBER WIND TUNNEL DATA

FIGURE 7

LANDING LIFT - ATTITUDE LIMITED

Approach lift coefficient would require a relatively high angle of attack for the programmed flap position that gives the best L/D. After passing the airport boundary, the programmed flaps would transition to the touchdown flap, speed would bleed off during flare, and touchdown would occur with some clearance margin to structural contact.



LIFT - LOW REYNOLDS NUMBER WIND TUNNEL DATA

FIGURE 8

GROUND CLEARANCE MARGINS

Typical ground clearance margins for liftoff and touchdown are shown on a pitch-roll clearance plot. These margins must be adequate to give the clearances required to handle TASST abuse conditions and the real-life problems of cross-wind landings, gusts, etc. Clearance margins can be improved with longer landing gear, wing shear, etc., but at some cost in weight and complexity.

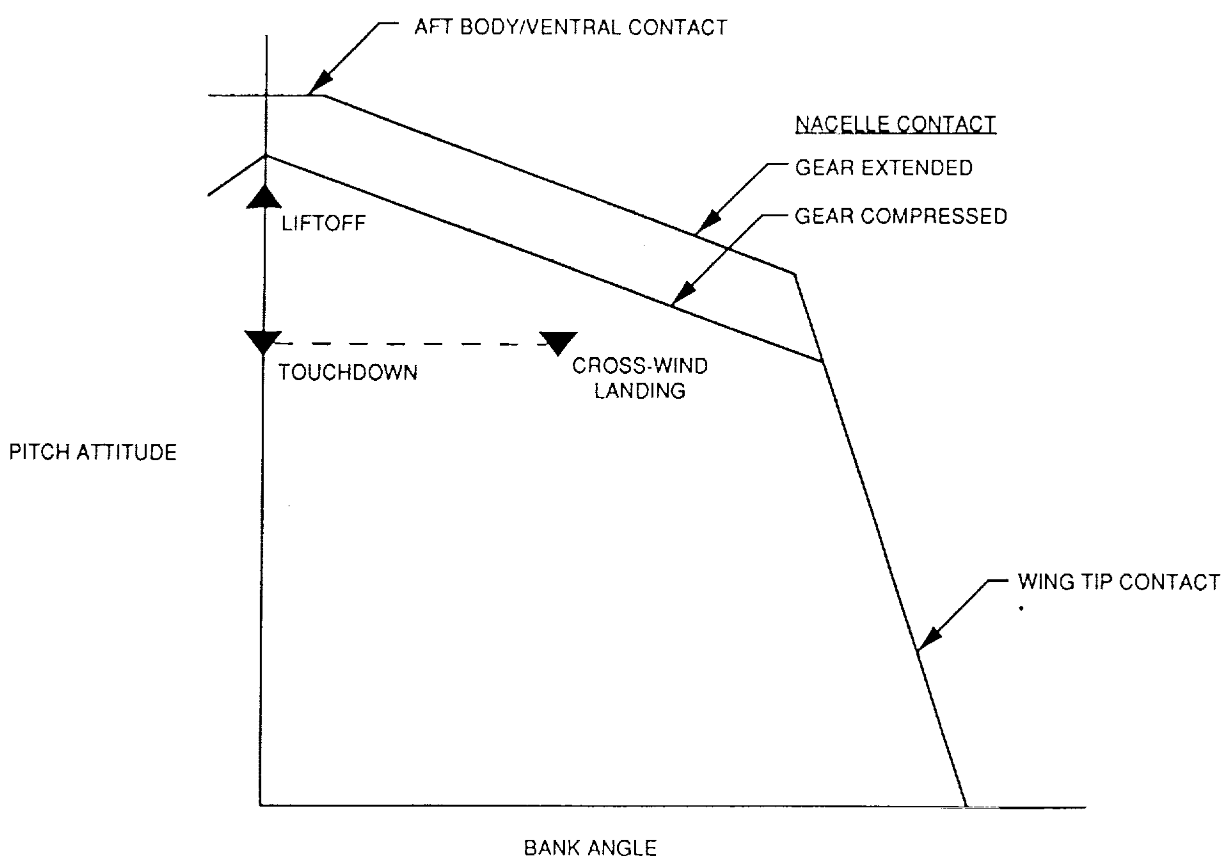
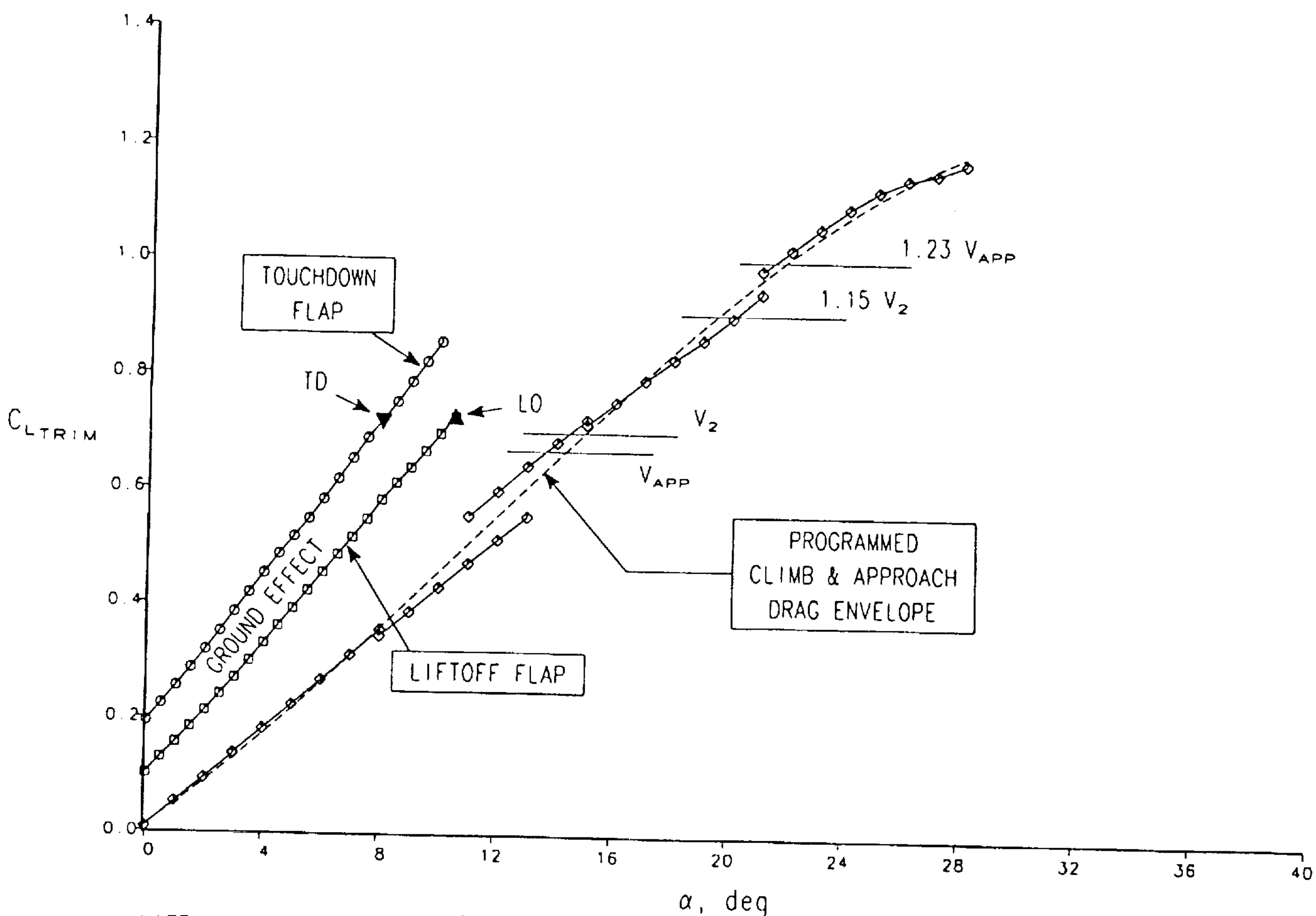


FIGURE 9

LIFT FOR MINIMUM DEMONSTRATED SPEEDS

A feature of the programmed flap system that could be included would be to adjust the flaps as angle of attack increases to give good characteristics for minimum speed demonstration and contribute to recovery if stall were to occur. The normal in-flight low speed configuration would be the flaps for maximum L/D at any angle of attack. This objective could be maintained as pitch attitude increased to the Vmin demonstrated condition. If an attitude over-shoot occurred, the flap could further transition to a best recovery flap. The liftoff flap and the touchdown flap would also be included so that a single flap configuration would exist at excessive angles of attack.

Several segments of fixed flap data are shown below through which a line is drawn representing the programmed flap function. The lift coefficient for Vmin required for the approach speed is more critical than for takeoff. It is still less than that available from the wind tunnel model, however.

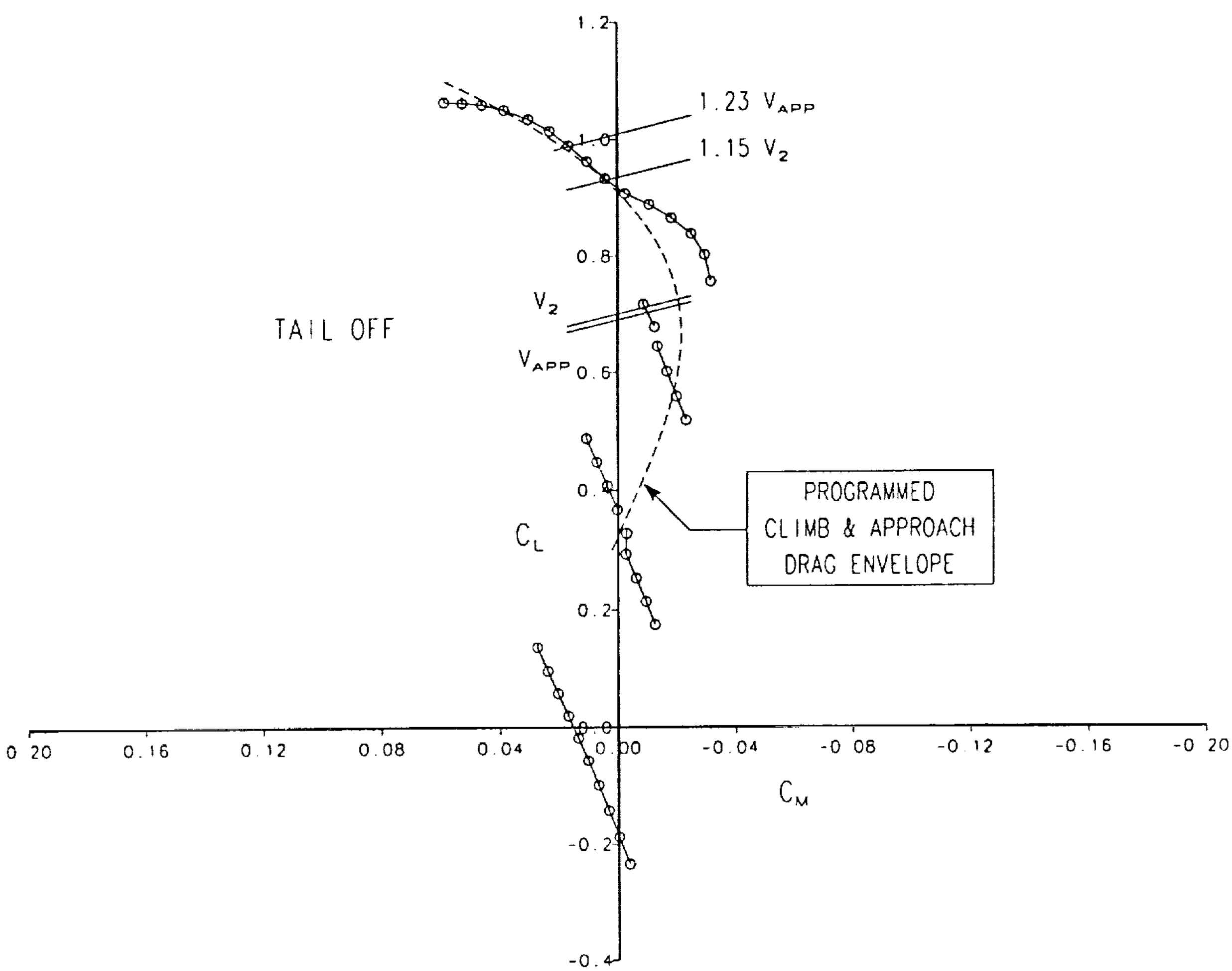


LIFT - LOW REYNOLDS NUMBER WIND TUNNEL DATA

FIGURE 10

<u>PITCHING MOMENT FOR MINIMUM DEMONSTRATED SPEEDS</u>

Some tendency to pitch-up exists at high lift coefficient, but the airplane is nearly trimmed for the Vmin conditions. Strong recovery capability from the horizontal tail is still possible.



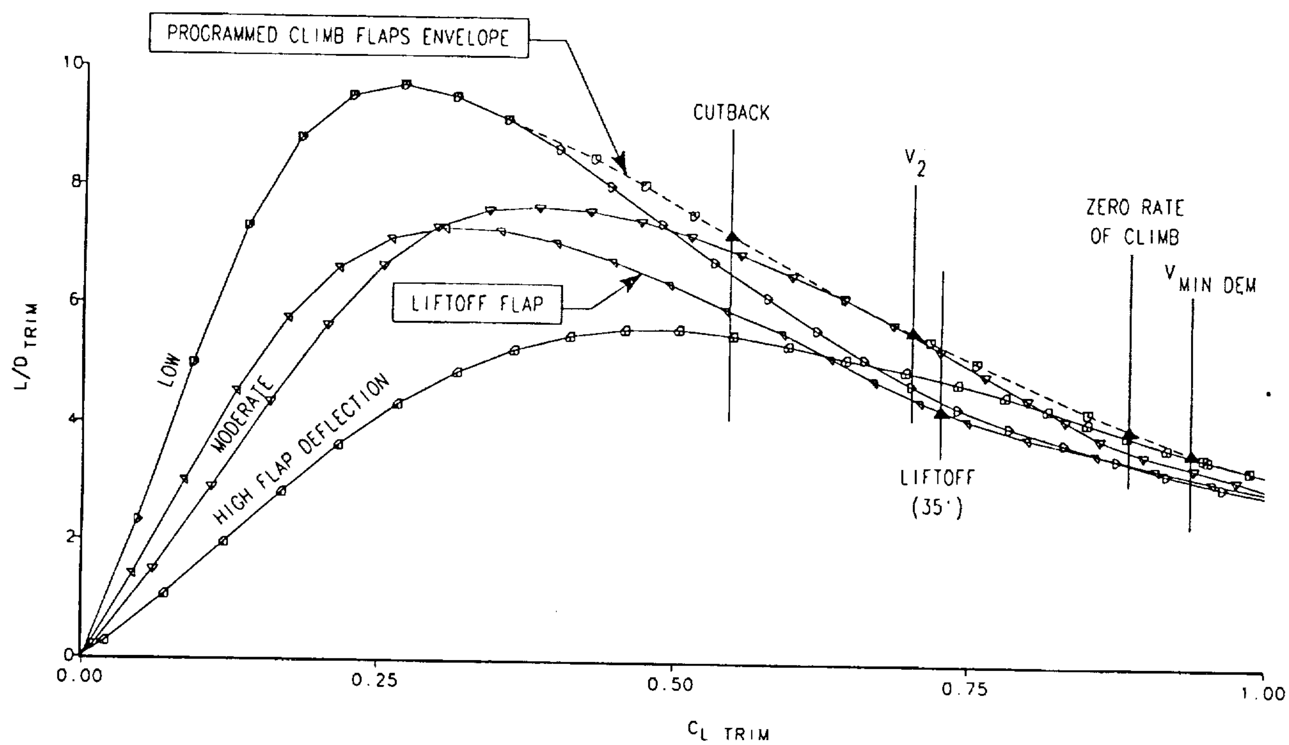
LIFT & MOMEMT - LOW REYNOLDS NUMBER WIND TUNNEL DATA

FIGURE 11

DRAG WITH REQUIRED TAKEOFF LIFT

The drag characteristics with the selected takeoff flaps and speeds are shown below. The liftoff flap gives a lower L/D because higher lift coefficients are the objective. Beginning transition to the scheduled flaps for better L/D after reaching 35 feet gives noticeable improvement by the gear-up point (V2). Further flap change and acceleration (lower lift coefficient) by the noise cutback point provides a significant improvement in L/D over that of the liftoff flap. If a fixed flap were required for takeoff, a compromised flap would have to be found, having less lift capability but better drag characteristics that the flap chosen for this study.

The zero-rate-of-climb condition and the minimum speed demonstration point are also on the best drag envelope.

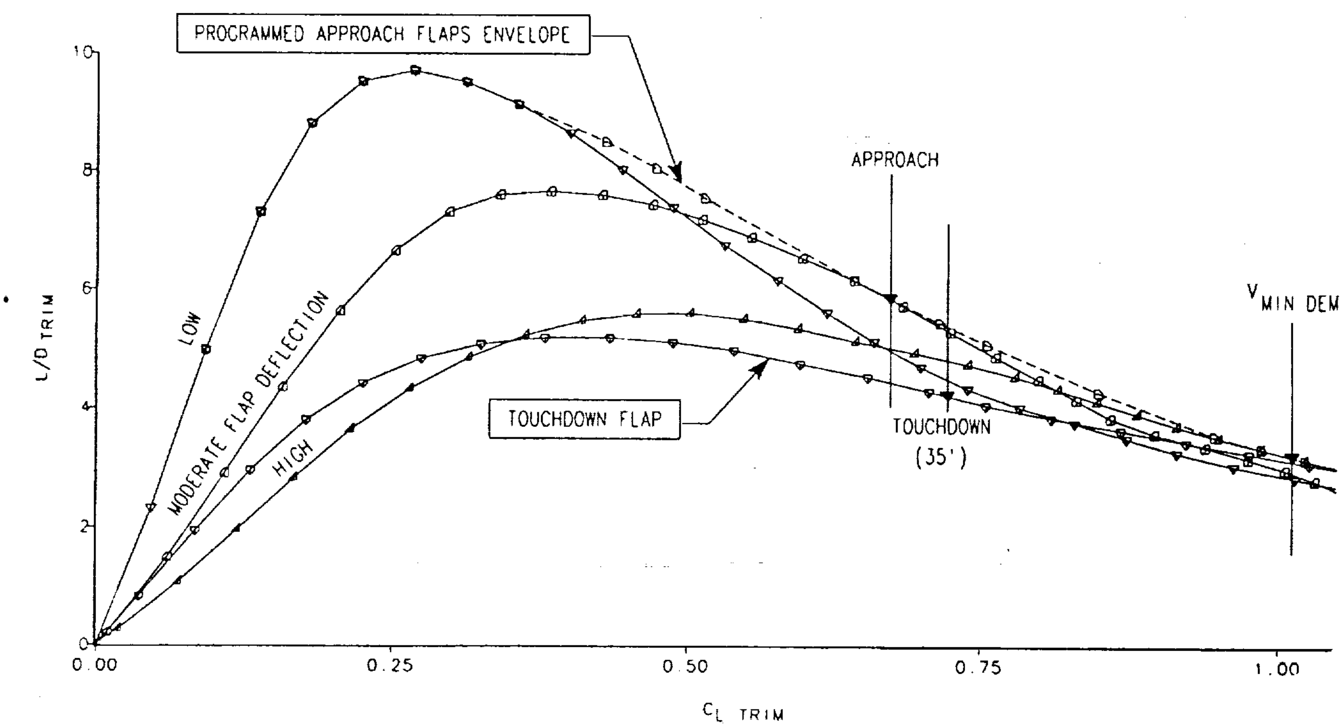


GEAR UP POLARS - LOW REYNOLDS NUMBER WIND TUNNEL TEST

FIGURE 12

DRAG WITH REQUIRED LANDING LIFT

the approach flight segment would be on the envelope for minimum drag. After passing over the airport boundary, the flaps would begin to transition to the touchdown flap. Since higher lift is desired to allow reduced touchdown attitudes, vortex lift from separated leading edges would be favored. The resulting drag increase would contribute to speed bleed-off. In order to maintain a fairly stable pitch attitude, the rate of flap extension may have to be coupled with automatic trim adjustments. Flare would occur with the increased lift due to ground effect.



GEAR UP POLARS - LOW REYNOLDS NUMBER WIND TUNNEL TEST

FIGURE 13

CLIMB GRADIENT REQUIREMENTS

The TASSTs expand on the climb requirements of the FARs by adding the Zero Rate of Climb and the Continued Approach conditions. In addition, four conditions must also be demonstrated maneuvering at 18 degrees of bank.

Zero rate of climb demonstration is part of the requirements for safe flight at high angles of attack, near the minimum demonstrated speed. Takeoff speeds would have a margin relative to Vzrc.

Continued Approach is a measure of the ability to safely continue approach following the loss of two engines.

Climb under maneuver conditions would account for the rapid drag build-up of low aspect ratio wings as lift is increased.

These gradient requirements can be used to calculate how low a drag level is required for the cruise-sized airplane to have adequate low speed performance.

Tentative Airworthiness Standards For Supersonic Transport (TASST)
(1971)

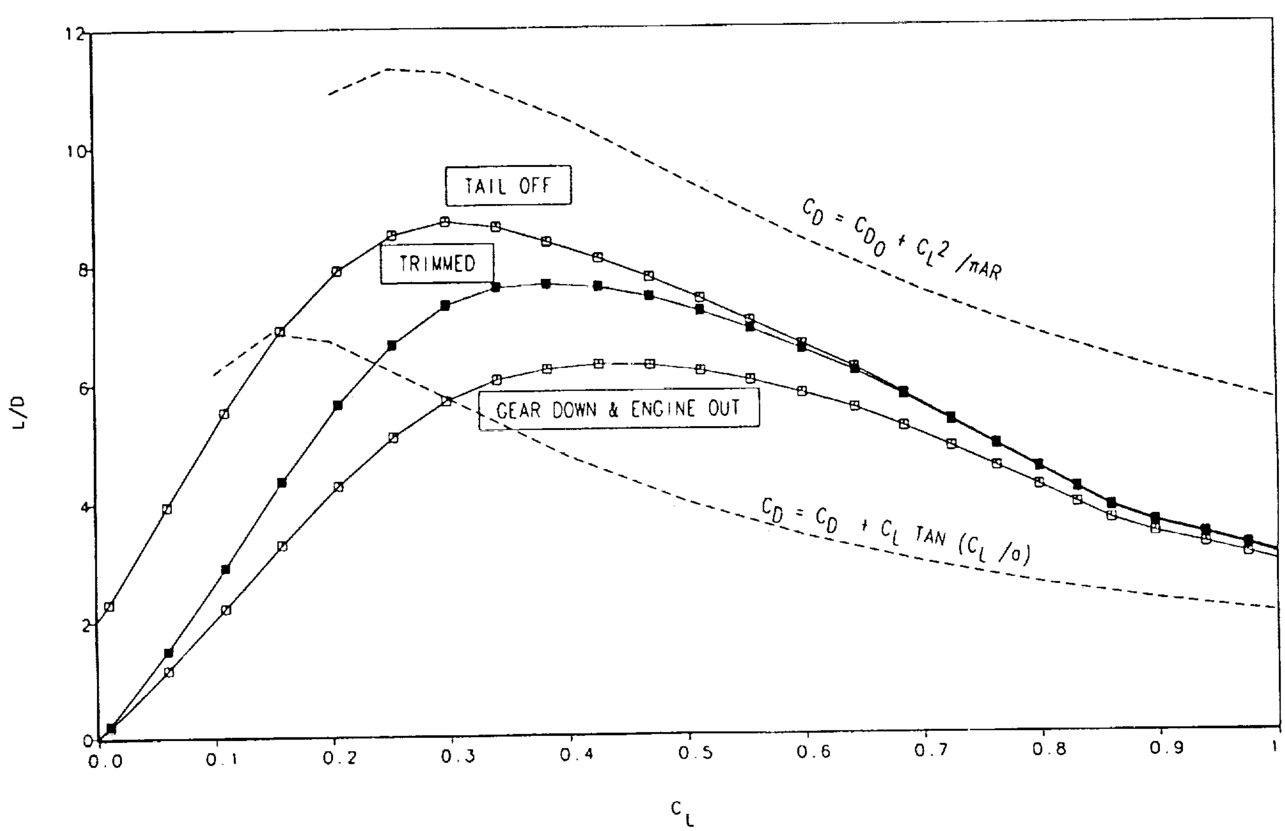
Condition	Gradient Req'd $\varnothing=0$	Gradient Req'd $\varnothing=18°$	NO. ENG	GEAR	Specified Conditions FLAP	THRUST	V
Takeoff Climb							
- First segment	.005	-	3	Down	Liftoff	(1)	V_{LOF}
- Sec Segment	.030	.020	3	Up	When Gear is Fully Retracted	(2)	V_2
- Zero R/C	0	-	3	Up	Takeoff Configuration	T.O.	$\leq V_2/1.125$
Landing Climb							
- Approach	.027	.017	3	Up	Approach	T.O.	V_{APP}
- Continued Approach	.024	.014	2	Up	8 sec (3)	8 sec	V_{APP}
- Landing	.032	.022	4	Down	Landing	8 sec	V_{APP}

(1) Most Critical Propulsion Configuration to Gear Up.
(2) Most Critical Propulsion Configuration to 400 ft.
(3) Flaps or Thrust Avialable in 8 sec

FIGURE 14

INCREMENTS TO BASIC DRAG

The basic drag of a wing-body must be trimmed and landing gear and engine-out drag added before the climb gradients are determined. Results for one flap position and trim balance point is shown. Theoretical drag polars bracket the wind-tunnel results except at low lift levels where flap drag is excessive.



POLARS - LOW REYNOLDS NUMBER WIND TUNNEL DATA (ENGINE-OUT DRAG ESTIMATED)

FIGURE 15

L/D REQUIRED FOR CLIMB

When comparing the basic trimmed drag levels required to meet the various climb gradient requirements, it is necessary to account for landing gear drag and engine-out drag increments. Several gradient requirements can then be compared to wind-tunnel results for a symmetric model with gear off.

- Climb equation

$$\text{Tan}\,\gamma = T/W - [D/L + \Delta D/L_{eo} + \Delta D/L_{gear}]$$

- $L/D_{required}$ (symmetric thrust and gear up)

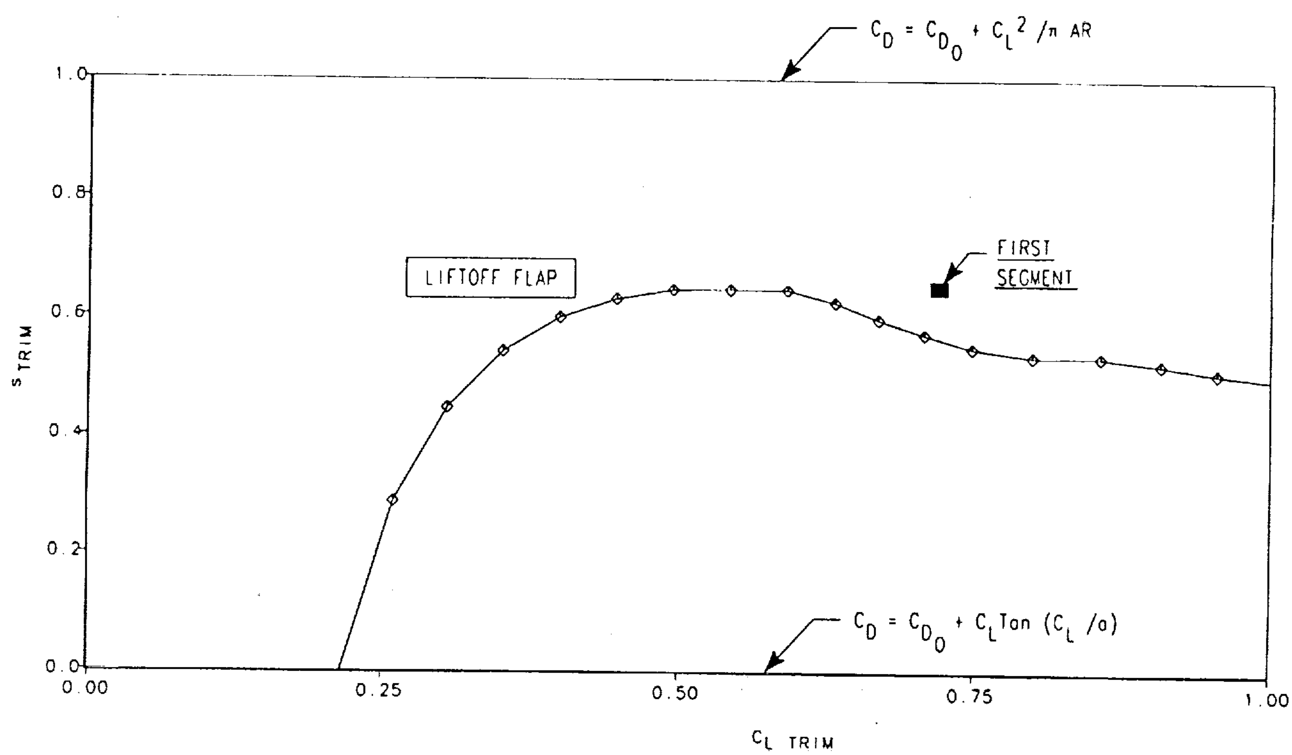
$$L/D_{req'd} = \frac{1}{[T/W_{avail.} - \Delta D/L_{eo} - \Delta D/L_{gear}] - \text{Tan}\,\gamma_{req'd}}$$

FIGURE 16

POLAR POINT REQUIRED FOR FIRST SEGMENT CLIMB

This and following charts are shown using the suction parameter, s, which is a measure of induced drag efficiency. Ideal polars consisting of skin friction and elliptic span loading induced drag define s=1, as low a drag level as possible. Completely separated flat plate induced drag plus skin friction define s=0. This parameter is a measure of drag efficiency and more independent of planform effects than is lift-to-drag ratio.

First Segment Climb is at 35 feet of altitude, the gear is still down and one engine is inoperative. The required drag level for First Segment Climb is less than the wind tunnel data used for the liftoff flap polar. A better liftoff L/D is needed, but the liftoff angle of attack might be compromised if adjustment in flap position, closer to the programmed flap envelope, is used.

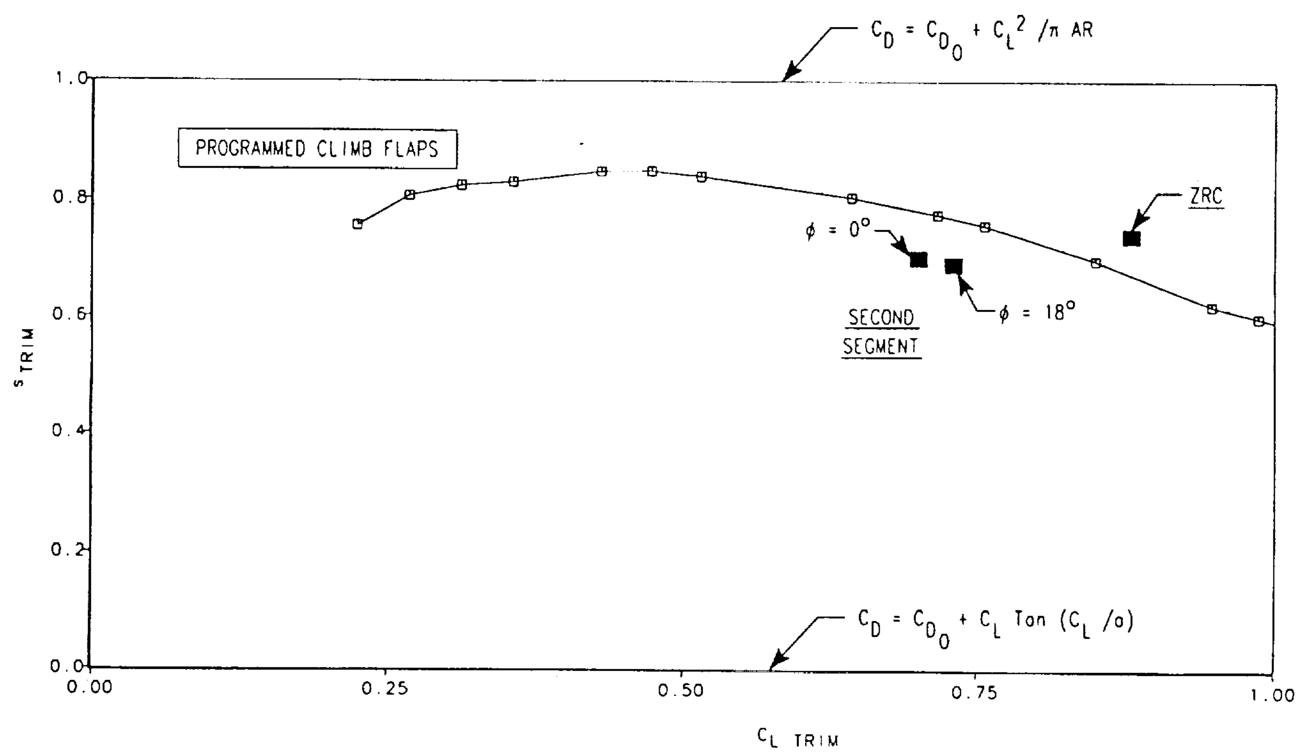


ALL ENGINE/GEAR UP POLAR - LOW REYNOLDS NUMBER WIND TUNNEL DATA

FIGURE 17

POLAR POINTS REQUIRED FOR SECOND SEGMENT CLIMB AND ZERO RATE OF CLIMB

Second Segment Climb and Zero Rate of Climb requirements are with gear up and one engine inoperative. The wind tunnel polars being used for programmed climb flaps are better than the drag levels required to meet Second Segment gradients, even for the maneuver condition. The polars are deficient relative to the Zero Rate of Climb gradient drag, however.



ALL ENGINE/GEAR UP POLAR - LOW REYNOLDS NUMBER WIND TUNNEL DATA

FIGURE 18

POLAR POINTS REQUIRED FOR CONTINUED APPROACH

Since maximum landing gross weight is much less than maximum takeoff weight, the thrust-to-weight ratio is higher. This makes it easier to meet the climb gradient requirements associated with landing.

On the figure below, only Continued Approach shows up, the required points for Approach and Landing Climb are below the s=0 line. Continued Approach requirements are with two engines inoperative but with gear up. Even so, the wind tunnel polars are better than required, even if the requirement had to be met with the higher drag touchdown flap.

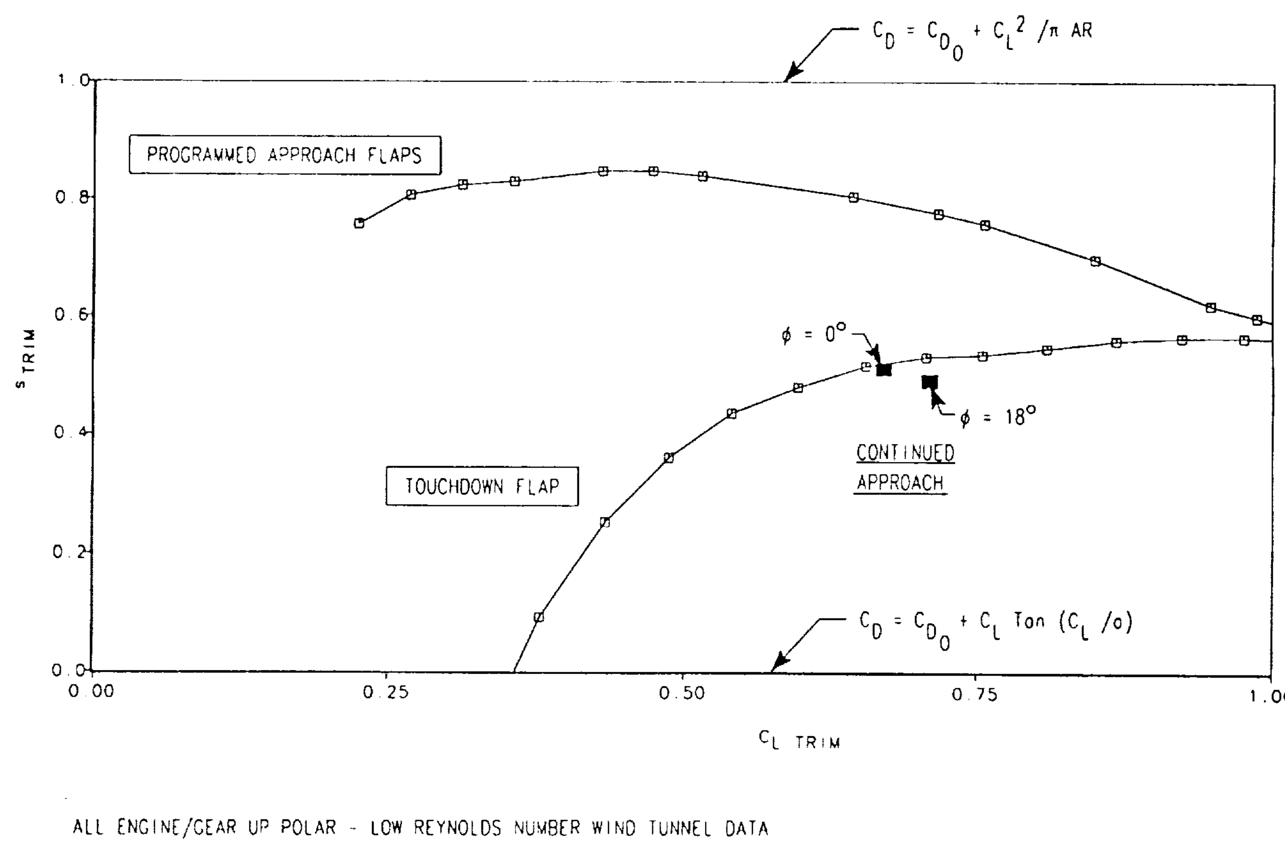


FIGURE 19

DRAG EFFECTS ON NOISE

Community noise is a critical and designing constraint on the HSCT. Reducing drag to improve the noise characteristics is one of our principal goals. Reduced drag contributes in a number of ways but also has some limitations as noted below.

CLIMB

- Reduced climb drag has only a small effect on sideline noise
  - Need operational techniques - programmed lapse rate (PLR)
  - Need improved engine design and noise supression
- Reduced drag improves the climb profile:
  - More height gained by cutback
  - More acceleration along the flight path
- Reduced drag allows a deeper cutback to lower thrust levels
  - Required climb gradient after spindown
    - 4% (all engine)
      or, if more critical
    - 0% (engine-out)

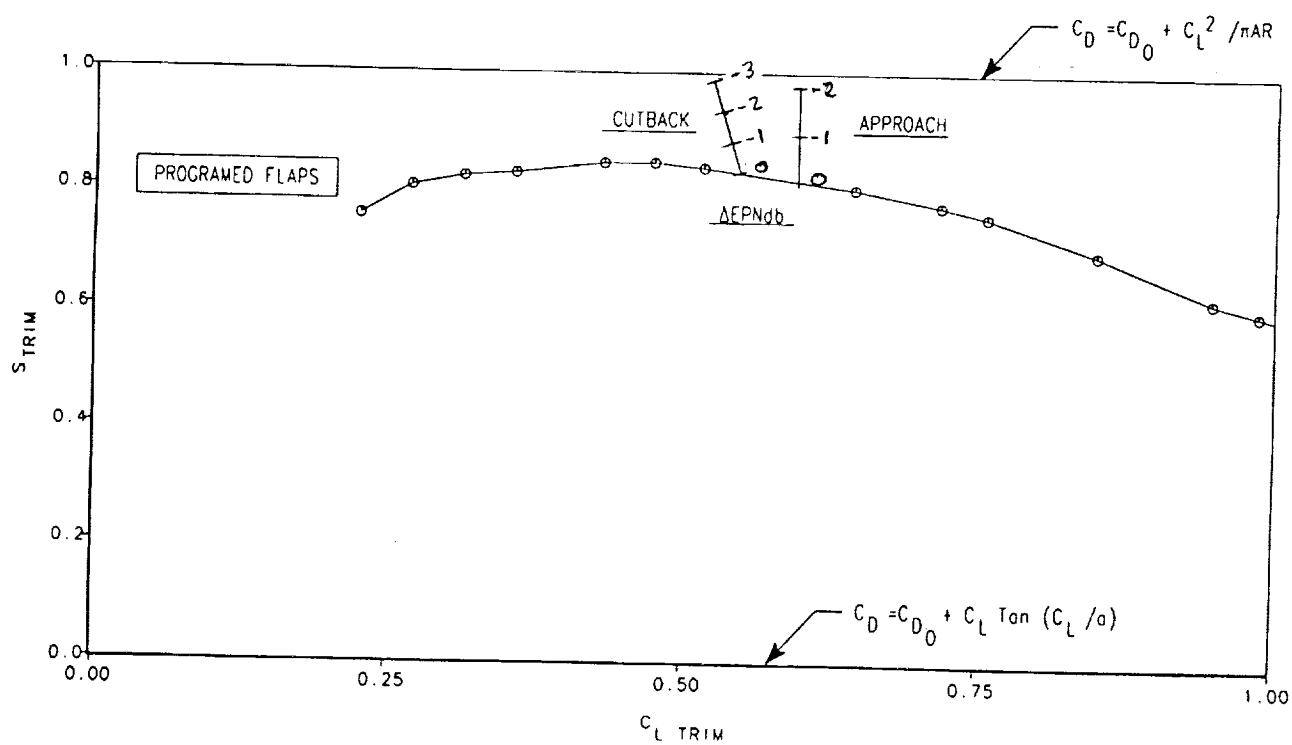
APPROACH

- Reduced drag lowers engine thrust required
  - Inlet may unchoke
  - Idle thrust may become limiting
  - Airframe noise may become more important

FIGURE 20

NOISE SENSITIVITY AT CUTBACK AND APPROACH

Cutback and approach noise conditions require lift coefficients of 0.5 to 0.6 and are close to the maximum drag efficiency for the wind tunnel polars with flaps programmed for minimum drag. Cutback noise is 50% more sensitive to improvements in drag than is approach noise. Some potential for reducing drag still exists. One to two EPNdb reduction may be possible.



GEAR UP POLAR - LOW REYNOLDS NUMBER WIND TUNNEL DATA

FIGURE 21

CONCLUSIONS

This study had as its objective the identification of the lift and drag levels that were required to meet the performance requirements of tentative airworthiness standards established at the time of the USSST program in 1971 and that were important to community noise. Research to improve the low speed aerodynamic characteristics of the HSCT needs to be focused in the areas of performance deficiency and where noise can be reduced. Otherwise, the wing planform, engine cycle, or other parameters for a superior cruising airplane would have to be changed.

- **Operating the flaps in the most effective way along the low speed flight profiles significantly improves low speed performance and noise.**

- **For this study configuration, relative to the tentative airworthiness standards being worked on in 1971:**

  - **Lift levels are achievable with programmed flaps**
  - **The critical drag conditions are first segment and zero rate of climb.**

- **For this study configuration:**

  - **Cutback noise is more sensitive to drag reduction than is approach noise.**

  - **The potential exists for one to two EPNdb from drag reduction.**

FIGURE 22

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