FLIGHT CHARACTERISTICS

TABLE OF CONTENTS

GENERAL

This aircraft operates within an exceptionally large Mach number and altitude envelope but the equivalent airspeed, angle of attack, and load factor envelope is relatively narrow. Typical takeoff and landing speeds are 210 and 145 knots respectively, and the cruise speed is approximately 1850 knots at 3.2 Mach number. Sustained cruise altitudes at high Mach number range from 74,000 feet to above 85,000 feet.

The aircraft is designed to obtain maximum cruise performance at 3.2 Mach number. The external configuration, air inlet system, power-plant and fuel system sequencing are optimized for this flight condition. A three axes stability augmentation system is an integral part of the aircraft control system design and is normally used for all flight conditions. The normal flight characteristic discussed in this section assume proper SAS operation, unless stated otherwise, and observance of the limits specified in Section V.

CONFIGURATION EFFECTS

External configuration features which affect flight characteristics include the delta wing, fuselage chines and the engine nacelle location.

The normal delta wing characteristics are present in these aircraft. There is no stall at normal operating speeds and flight attitudes, instead there is a large increase in drag as the limit angle of attack is approached. This characteristic of a delta wing can cause very high rates of sink to develop if the aircraft is flown at too slow a speed. The stall warning light is to limit the angle of attack to a safe value so that stall is not encountered.

The dihedral effect is positive, but diminishes at the higher Mach numbers. Roll damping is relatively low over the entire speed range of these aircraft and the lateral-directional qualities are relatively poor with SAS off.

The chines extend from the fuselage nose to the wing leading edge. At subsonic speeds they have the beneficial effect of increasing directional stability with increasing angle of attack. At supersonic speeds, they provide lift and eliminate a need for canard surfaces or special nose up trimming devices. The automatic fuel tank sequencing shifts the center of gravity aft during acceleration to correspond with the aft shift of center of lift with increasing Mach. Then it maintains c. g. at a relatively constant optimum location during cruise. This placement of the center of gravity close to the center of lift decreases pitch trim requirements and minimizes the thrust and fuel flow required for cruise. This also reduces the static longitudinal stability margin, but the SAS compensates for the reduction and provides satisfactory handling qualities.

The mid span location of the engines minimizes drag and interference effects of the fuselage. The inboard cant and droop of the nacelles gives maximum pressure recovery at the engine inlets at the angles of attack normal for high altitude supersonic cruise. However, the location results in sensitivity of the aircraft to asymmetric thrust conditions. During afterburner cruise, throttle and EGT trim adjustment to equalize fuel flows minimizes thrust differences. Engine EGT and fuel flow values should be matched by throttle adjustments during subsonic cruise. Indicated flows during non-afterburning operation may include heat sink system requirements after hot flight with low fuel remaining, so that flowmeter values may not be representative of engine consumption and thrust.

STABILITY CHARACTERISTICS

The augmented dynamic stability is positive and flight tests have demonstrated that the dynamic damping characteristics are essentially deadbeat. No unusual static stability characteristics have been disclosed when operating within the c. g. and angle of attack limits. Positive static stability continues to exist when c. g. is somewhat aft of the limit while at intermediate supersonic speeds (from Mach 1.2 to at least Mach 2.6.) However, if the aft c. g. limit is violated while near the design cruise Mach number, a static instability in pitch may be experienced. If pitch rates are then generated and not arrested within the angle of attack limit, a pitch up can develop and result in structural failure of the aircraft.

The aircraft is controllable without stability augmentation to Mach 3.2. Without SAS it is also controllable during climb and descent, during inlet unstart up to Mach 2.8 and 430 KEAS and during unstart and engine flame out up to Mach 2.5 and during twenty degree bank turns in heavy turbulence at

WING LIFT VS ANGLE OF ATTACK

BASIS: Wind Tunnel Tests
Rigid Airplane

NOTE: No wing stall experienced

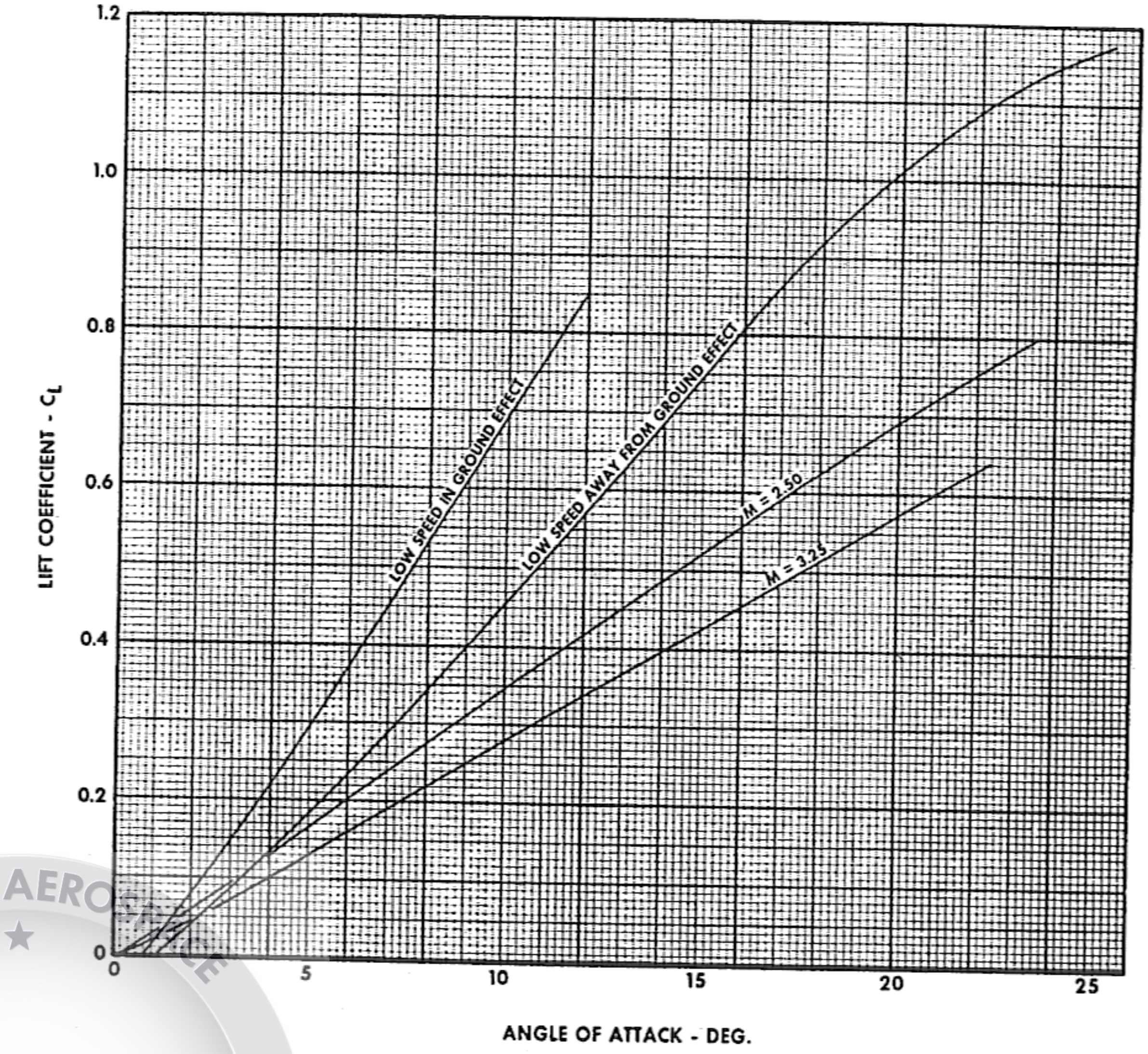
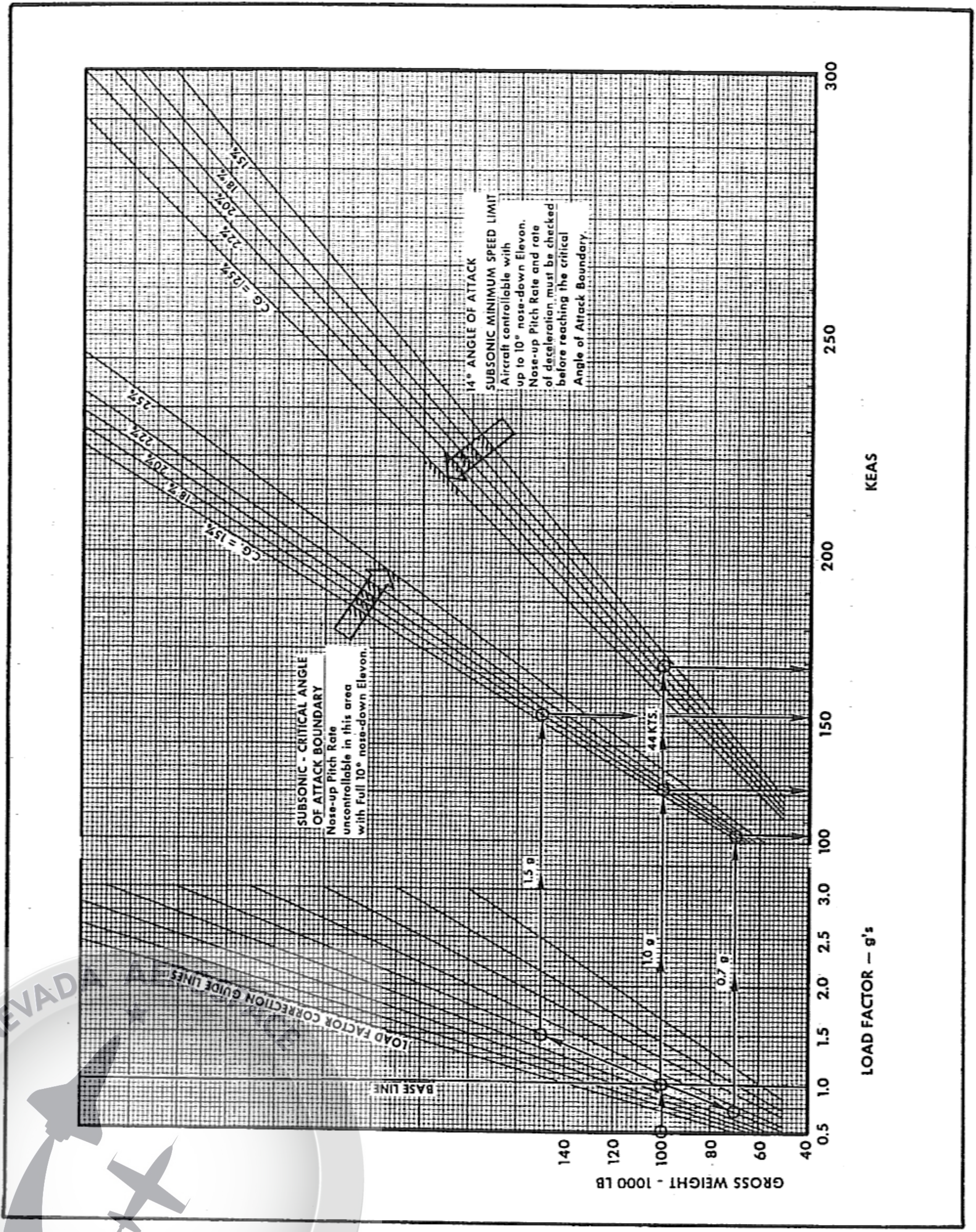


Figure 6-1

SUBSONIC - CRITICAL ANGLE OF ATTACK BOUNDARY



14° ANGLE OF ATTACK

SUBSONIC MINIMUM SPEED LIMIT

Aircraft controllable with up to 10° nose-down Elevon. Nose-up Pitch Rate and rate of deceleration must be checked before reaching the critical Angle of Attack Boundary.

SUBSONIC - CRITICAL ANGLE OF ATTACK BOUNDARY

Nose-up Pitch Rate uncontrollable in this area with Full 10° nose-down Elevon.

Figure 6-2

low supersonic and transonic Mach numbers. However, control with SAS off is sensitive and control movements should be kept to the necessary minimum. Thrust asymmetry should be minimized, particularly at the higher Mach numbers. Sustained cruise or maneuvering without pitch and yaw axis stability augmentation is not recommended near design speed.

At cruise Mach number, the pitch stability is only slightly positive and disturbances are only lightly damped. Sudden loss of all pitch SAS while in maneuvering flight will cause a pitch transient which will momentarily increase the load factor for the same stick position.

Without SAS the yaw stability may vary from positive to very slowly divergent. Response of the automatic air inlet system to yaw oscillation has a pronounced effect on directional motion of the aircraft. Unless controlled by the pilot, phasing of the spikes and forward bypass can tend to either drive or damp the yaw oscillations.

Emergency operating procedures for use in the event of SAS failure are given in Section III.

HIGH ANGLE OF ATTACK CONDITIONS

Minimum airspeed restrictions and a maximum angle of attack warning light are furnished to prevent approach to pitch-up conditions, and to maintain adequate ground clearance at takeoff and landing consistent with performance objectives. There is no stall in the classic sense where an abrupt loss in lift would occur at a critical angle of attack. (See Figure 6-1, Lift vs Angle of Attack.) A nose up pitching moment develops instead, as angle of attack increases, which becomes uncontrollable with full nose down elevon as the critical angle of attack boundary is reached. (See Figure 6-2, Subsonic Critical Angle of Attack Boundary.) An uncontrollable pitch-up will not occur until after limit angle of attack as given in Section V is reached. The SAS will tend to maintain apparent stability about all three axes until loss of control occurs, then the aircraft will pitch-up with little or no warning. Note that there is an airspeed margin of from 30 to 75 KIAS when subsonic and at the aft c.g. limit of 25% MAC. The margin is less at supersonic speeds and varies with Mach number. c.g.'s aft of normal limits will materially reduce the margin. When near limit angle of attack, a pilot induced rapid nose up pitch rate may require more margin for recovery than is available.

WARNING

> An uncontrollable pitch-up maneuver will result when the critical angle of attack boundary is reached. Recovery from this condition is extremely unlikely. Attempted recovery must not be continued to the point where insufficient altitude for recovery or ejection exists.

Pitch rates which accompany increasing angles of attack must be checked and load factor relieved at a sufficient rate to increase airspeed when the critical angle of attack boundary is approached. When subsonic and terrain clearance permits, airspeed should be increased to 300-350 KIAS before resuming level flight. Care must be exercised to insure that recovery load factors will neither cause limit angle of attack to recur or impose load factors beyond allowable values. When supersonic and near limit Mach number, it may be necessary to reduce power or increase drag (or both) while recovering so that limit Mach number will not be exceeded while airspeed is increasing.

SPINS

Intentional spins are prohibited. The following technique is suggested in the event of an inadvertent spin; however, ejection may be the best course of action after considering existing altitude, airspeed, spin rate, attitude, and fuel loading conditions, as spin recovery has not be demonstrated and is considered extremely unlikely. At the pilot's discretion:

1. Center the controls, disengage surface limiters, and determine the direction of rotation from the turn indicator.
2. Apply forward stick and full roll control into the direction of spin as the nose drops.
3. Apply opposite rudder to stop rotation.
4. Center the rudder and roll control as rotation stops.
5. Start pull-out at 300 to 350 KIAS.
6. If possible, avoid exceeding 450 KIAS and limit load factor during recovery.

WARNING

With uncontrollable conditions, eject at least 15,000 feet above the terrain whenever possible.

CONTROL EFFECTIVENESS

Generally control effectiveness is good. At high altitude and angle of attack roll control effectiveness is reduced. This is only a problem if an unstart occurs in the down inlet in a turn. Refer to Inlet Duct Unstarts, Section III.

SINGLE ENGINE

The yawing moment resulting from asymmetric thrust is large if an engine fails just after takeoff or a single engine go around is necessary. Approximately 2/3 to full rudder deflection and 10 degrees or more bank into the good engine will be necessary to maintain control immediately after loss of power. Drag can then be minimized by reducing pedal force and trimming to 7^{o} to 9^{o} rudder position indication, simultaneously using bank and sideslip toward the operating engine as necessary to maintain the desired flight path. The SAS automatically responds with corrective control at the time of engine failure or go around power application and its response rate is faster than pilot reaction time. However, rudder control follow up by the pilot is necessary as the yaw SAS authority is limited to 8 degrees rudder deflection. The SAS continues to apply rudder deflection as long as a sideslip is maintained, but this deflection is not indicated by pedal position or by the rudder trim indicator.

The amount of rudder deflection required during single engine operation decreases as airspeed is increased. During single engine cruise at 0.5 to 0.85 Mach number, the aircraft can maintain course with surface limiters engaged. Optimum rudder deflections are maintained by the SAS without using rudder trim when bank and sideslip toward the operating engine are used to maintain course. The bank angles required approach 10^{o}.

Above Mach 2.8, engine failure, flameout or inlet unstart may require yaw axis stability augmentation to avoid excessive sideslip and bank angles which could cause the operative engine to stall or flameout. Inlet unstarts while at 450 KEAS and maximum power are quite severe. In these cases, unassisted pilot reaction is too slow to provide all the control immediately required. Pilot follow up is necessary after the initial SAS corrections.

NOTE

> Before retarding the throttle to shutdown an engine, care must be exercised to properly identify the side on which the malfunction occurred. There have been cases where the operative engine was improperly identified as the source of the problem.

NORMAL OPERATING CHARACTERISTICS

Refer to Appendix I for specific performance information.

Takeoff

The aircraft accelerates rapidly to rotation speed once maximum thrust is set during takeoff. The nosewheel can be lifted 50 to 60 knots below takeoff speed, but this is not advised because the drag that is created decreases the acceleration and extends the takeoff run. With zero degrees pitch trim, a stick force of approximately 25 pounds is normally required to lift the nosewheel at rotation speed. Stick force must be relaxed during the rotation in order to check the nose up pitch rate. During maximum performance takeoffs, speed and attitude must be monitored carefully to avoid over-rotating and dragging the tail.

Climb

Normal climbs to supersonic cruise speeds involve three phases of operation. These consist of a subsonic climb, a transonic acceleration to the supersonic climb schedule, and a supersonic climbing acceleration.

There are no unusual characteristics during the subsonic phase except that a light airframe buffet may be felt near 0.9 Mach number as airflow conditions near the tertiary doors and ejector flap areas change

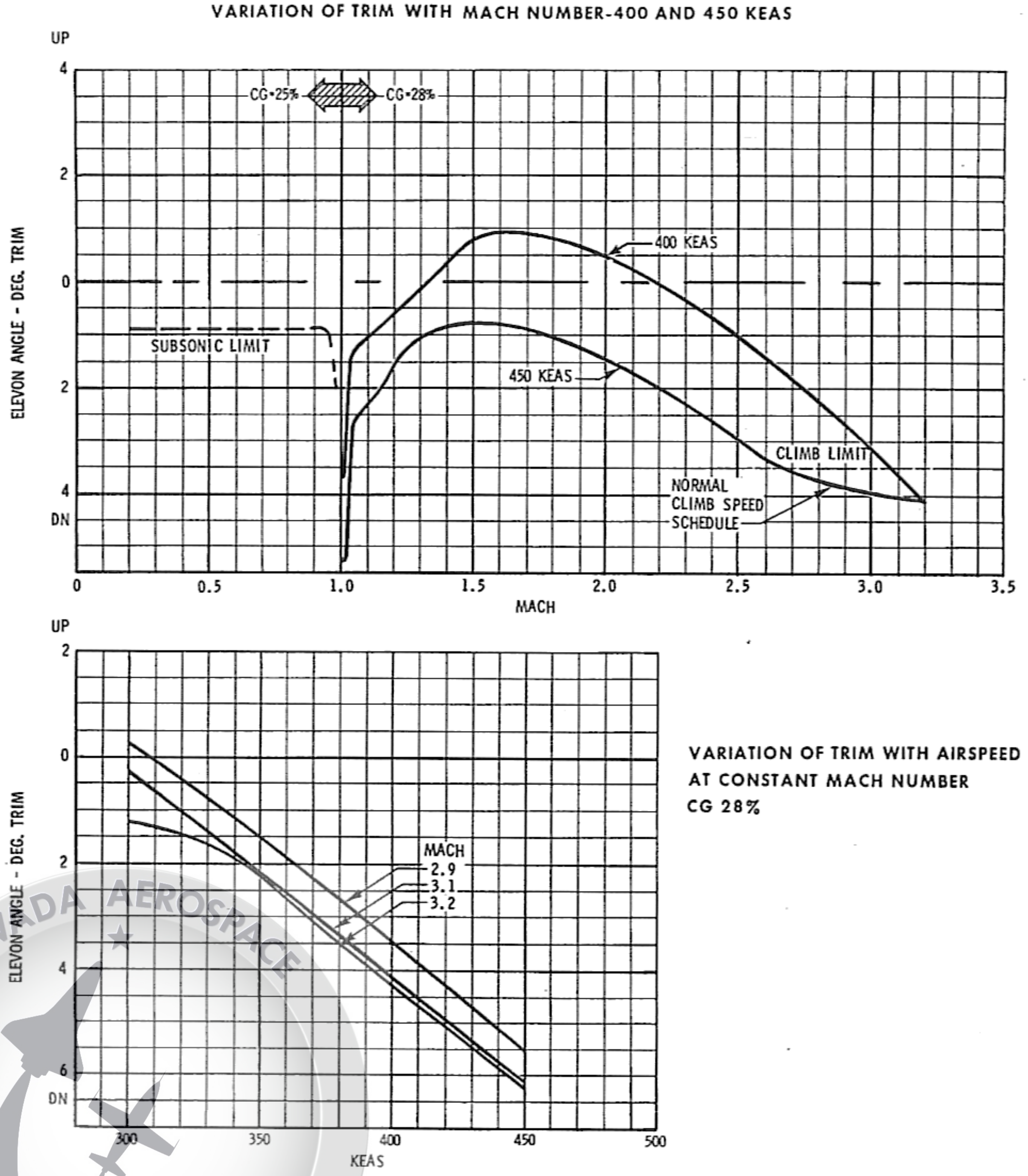
A Mach jump on the TDI instrument will be observed between 0.98 and 1.03 Mach number during transition to the supersonic climb speed schedule. No unique characteristics occur in this area; however, there is an area of decreased excess thrust from Mach 1.05 to Mach 1.15. A dive technique is used to improve acceleration through this speed range. The transition should be made without other maneuvering if possible, as even shallow turns increase drag sufficiently to decrease acceleration and increase fuel consumption considerably. A noticeable increase in acceleration can be expected after passing Mach 1.15. The pull up to establish climb attitude should be started 10-25 knots before the supersonic climb speed schedule is attained. This will reduce the possibility of overshooting the desired speed.

The supersonic climb is initiated when climb airspeed is established at approximately 30,000 feet. It is essential to maintain the schedule accurately to achieve best climb performance. Speeds which are higher than normal should be avoided because limit airspeed can be approached inadvertently in a short period of time.

The aircraft does not respond immediately to small pitch commands. This characteristic makes precise airspeed control difficult until experience is gained in the aircraft. If significant overspeed occurs, the recommended action is to reduce power until climb speed can be reestablished rather than pull up sharply and impose load factors.

ELEVON REQUIRED TO TRIM

ELEVON REQUIRED TO TRIM AT THE AFT CG CONDITION



VARIATION OF TRIM WITH MACH NUMBER-400 AND 450 KEAS

VARIATION OF TRIM WITH AIRSPEED AT CONSTANT MACH NUMBER CG 28%

Figure 6-3

A continual variation in trim is required during the acceleration to cruise speed, with the 450 KEAS schedule requiring more nose down trim than the 400 KEAS schedule. The variation of trim at the aft limit is illustrated by figure 6-3. This figure also shows the variation of trim required with airspeed when operating near the aft c. g. limits.

Occasional periods of inlet roughness may be encountered in the area between Mach 2.5 and 2.8. It may also be encountered at climb speeds in the region above Mach 3.0; however, the roughness diminishes as cruising altitudes are reached and the equivalent airspeed is reduced from the climb airspeed schedule.

The transition to cruise altitude and speed is accomplished with power being reduced slowly as the initial cruise altitude is approached.

Cruise

The following definitions have been adopted in order to categorize supersonic cruise operation.

a. Maximum range (optimum) cruise profile - This type of operation yields maximum range for the Mach number specified. Power settings used are in the lower portion of the afterburner range (near the 82° PLA throttle mark).

b. High altitude cruise profile - This type of operation yields altitude schedules which are above the maximum range and below the maximum ceiling profile. The specific range which results is less than for maximum range, but reasonably efficient cruising schedules are maintained.

c. Maximum ceiling profile - This type of operation requires continuous operation at near maximum afterburner power setting for the Mach number specified.

These types of operations employ a cruise climb that requires a gradual but continuous increase in altitude as fuel is consumed. The flight parameters are: Mach number, equivalent airspeed (KEAS) and altitude. These three variables are dependent upon one another. Gross weight, ambient temperature, and c. g. also have primary effects on performance capability.

Mach, KEAS, Altitude Relationship

The selection of the values for any two of the Mach, KEAS, or altitude variables automatically defines the value of the third. For instance, if cruise is scheduled for Mach 3.1 and the desired cruise altitude is initially 73,500 feet, the KEAS must be 395 knots.

Effect Of Changing Air Temperature

Ambient air temperature may appear to change abruptly as different air masses are encountered because of the high true airspeeds at cruise. Initially, if constant altitude is maintained, flight into a warmer air mass will cause a decrease in Mach number and KEAS, and the true airspeed (TAS) and compressor inlet temperature (CIT) will remain constant for a short time. A higher TAS and CIT will result as the desired Mach number is re-established. The opposite would occur as a result of flying into a colder air mass. New cruise altitudes are usually required to compensate for effects of variations in ambient air temperature.

Effect Of Mach Number

Another characteristic of supersonic cruise is that any given gross weight and CIT, the altitudes for maximum range or maximum ceiling profiles increase with Mach number. As a rule of thumb, this increase is approximately 1000 feet per 0.05 Mach number. A related characteristic is that if the Mach number is allowed to increase slightly above that desired, and if the throttle is not retarded, the aircraft has an increasing amount of excess thrust. It is easy to exceed target Mach number inadvertently.

Maximum Range (Optimum) Cruise Profile

At high Mach numbers, the maximum range (optimum) profile is a continuous cruise climb with the throttles in the afterburner range near the 82° PLA throttle mark. When at heavy weight, it may be necessary to initiate this type of profile by flying at a constant altitude for a short period, slightly higher than the altitude for best specific range, in order to maintain KEAS at or below maximum operating limits. In this case, the initial cruise altitude schedule remains above the optimum until gross weight is reduced sufficiently to allow establishment of a cruise climb. Cruise climb should not be continued above 85,000 feet (because of present operating restrictions).

Turns

Constant altitude turns with 30° bank angle can normally be made by increasing thrust. As a rule of thumb, fuel flow and angle of attack increase in proportion to load factor. It is more economical to allow altitude to decrease while turning, maintaining constant power setting and Mach number during the turn, and regaining the altitude lost upon rolling out. KEAS should not be allowed to increase above the maximum operating limits during descending turns.

Maximum Ceiling Profile

The maximum ceiling profile is 5000 to 6000 feet above the altitude schedule for maximum range. See Figure 6-4. Stabilizing the aircraft on a cruise climb profile wherein the aircraft is constantly flying at its absolute ceiling at maximum afterburner is very difficult. The only control the pilot has to maintain constant Mach number is to climb or descend. Therefore the maximum practical altitude can be obtained by using slightly less than full power.

High Altitude Cruise Profle

High altitude cruise profiles schedule the cruise climb altitude below the maximum afterburning ceiling. Continuous use of maximum afterburner is not required.

Effect Of Mach Decrease

The Mach number must not be allowed to decrease more than 0.05 Mach number below the desired cruise speed. A small decrease in Mach number and KEAS at constant altitude may cause the aircraft to intercept the ceiling for that speed and become thrust limited. A descent of several thousand feet may be required to re-establish the desired cruise Mach number.

NOTE

> Refer to Figure 6-4 for a summary of maximum range and ceiling altitudes for various Mach numbers, weights and ambient temperatures.

High Altitude Turn Technique

Turns Less Than 100°

The techniques described below minimize altitude variations while turning and abnormal altitude losses which can be encountered if turns are initiated near the maximum afterburner ceiling for the existing Mach number, gross weight and ambient temperature.

NOTE

> Mach 3.2 is the target speed recommended for turning when maximum altitude is the primary consideration.

c. When turn entry is scheduled from a high altitude cruise profile when at light weight and using partial afterburning for power settings:

1. Prior to turn, cruise at power required to maintain target Mach number at desired altitude. Mach 3.2 is recommended when minimum altitude loss is the primary consideration.

2. Turn Mach Hold OFF and leave the autopilot Attitude Hold mode engaged.

3. Enter the turn with throttles set below maximum afterburning. While turning, adjust the throttles as required to control Mach number and adjust the autopilot pitch trim wheel to control altitude. Cruise altitude can be maintained in most cases.

Note

Do not make abrupt pitch attitude changes.

4. After 30° of turn, allow altitude to increase 1000 feet if sufficient excess thrust is available.

5. After completing the turn, engage Mach Hold to maintain the desired cruise climb schedule, and use power as required.

Descent

Descent characteristics are not unusual except for the variation in flight path angle encountered during the supersonic deceleration. Normal deceleration techniques include maintaining an optimum KEAS schedule to obtain maximum range and prevent exceeding engine cooling limitations. When cruise KEAS is higher than optimum, altitude should be maintained after power reduction until KEAS decreases. When cruise KEAS is lower than optimum, descent should be started immediately after power reduction, maintaining cruise Mach number until desired KEAS is intercepted. The angle of descent varies from approximately 1° initially to approximately 7° as Mach 1.0 is reached.

Air Refueling

Air refueling of these aircraft with the flying boom system of the KC-135 tankers poses no problem of compatability and is normally accomplished between 25,000 and 32,000 feet. The aircraft provides an extremely stable platform with the SAS on. The only characteristic that causes some problem is that, without afterburning, the aircraft may become power limited at the higher refueling altitudes before a maximum onload can be completed. This requires using either a toboggan technique or a technique of completing the refueling with one afterburner on.

Forward visibility in the observation and precontact positions is excellent, but upward, downward, and aft visibility is restricted. Rendezvous is easiest from a slightly low position with the tanker within 60° either side of the nose. The pilot's refueling visibility is optimized by lowering his seat prior to contact. Depth perception through the vee windshield is slightly impaired, and some pilots may prefer to use one side of the windshield during contact.

A slight buffet will be felt as the contact position is reached. This is tanker downwash and has no effect on the receiver except for a slight decelerating effect. Acceleration response of the engines is excellent, and aircraft drag at refueling speeds produces correspondingly good deceleration response.

Overcontrol of the engines should be avoided while gaining and holding position due to nonlinearity of throttle position vs engine thrust. A given throttle angle change near military power yields more thrust change than a similar change in the throttle mid range. The aircraft may become power limited if the afterburner-on technique is not used, and tobogganing descents of up to 1000 feet per minute may be required as the military power throttle position is approached. Asymmetric thrust is easily controlled when the afterburner-on technique is used.

Light turbulence encountered while in contact poses no particular problem with SAS operating normally, and shallow turns of up to 20° bank angle can be made without difficulty. However, if all pitch SAS including the back-up pitch damper are inoperative, it is recommended that refueling not be attempted except in an emergency. The aircraft tends to be unstable without any pitch SAS, but control can be maintained under favorable conditions with fuel transferred to obtain a forward c.g. location.

All disconnects should be made with a rearward and slightly downward relative motion with wings level. This will insure separation of the boom from the receptacle with a straight line force. Side or rolling loads or excessive deviations from the desired elevation increase the possibility of boom and/or receptacle damage during disconnect.

Night refueling is essentially the same as for daytime operations except that added caution and effort is required to avoid overshoot, and the tendency toward throttle over-control while in contact is increased.

Approach and Landing

Handling characteristics during approach and landing with SAS operative are good. Short period disturbances are well damped, and rates of roll available for maneuvering are adequate. The aircraft can be held off the runway to speeds that are much lower than are recommended for landing. The touchdown attitude normally is from 10° to 12° angle of attack. There is a risk of damage to the aft fuselage if the touchdown attitude exceeds 14°.

Normally the aircraft is flown directly to touchdown rather than attempting to float just off the runway with subsequent settling at too high an attitude. Prompt chute deployment will result in momentary deceleration loads of up to one g. The chute should not be deployed in the air because of the rapid deceleration and rate of sink that could develop, but it can be actuated before nosewheel contact without any unusual pitching tendencies.

Practice landings with SAS off are not recommended. Approach control during emergency landings with all pitch SAS off is increasingly more difficult if c.g. approaches or exceeds the aft limit.