FLYING QUALITY REQUIREMENTS FOR THE AMST

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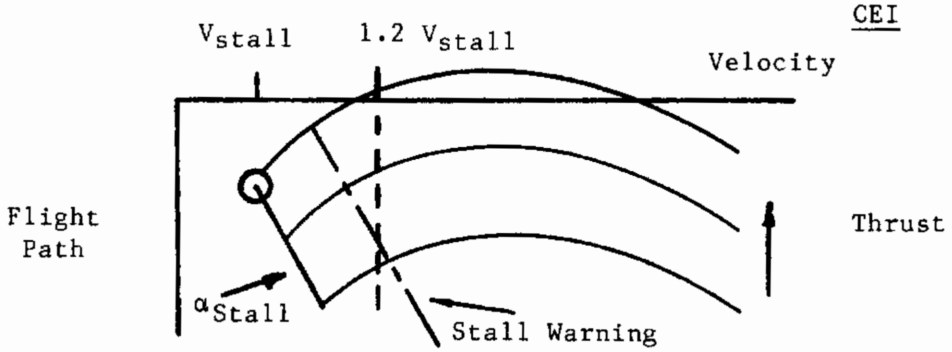
The major USAF flying qualities requirements for the production Advanced Medium STOL Transport (AMST) are discussed. The Military Specification for Flying Qualities of Piloted Airplanes (MIL-F-8785B, Reference 1) was modified by the Engineering Office of the AMST System Program Office (SPO) to account for powered lift and Short Takeoff and Landing (STOL) operation. These modifications were discussed thoroughly with the two AMST prototype contractors, various agencies of the USAF, including the Military Airlift Command, and the National Aeronautics and Space Administration (NASA). The primary tactical mission of the AMST is to carry a 27,000 pound payload 400 nautical miles into a 2100 foot long by 60 foot wide semi-prepared runway and then return. Landing at a 2100 foot field would have required the use of powered-lift, stability and command augmentation, low approach speeds, and operation further on the backside of the power required curve than normally experienced by large transports. Safe and routine operation into and out of the 2100 foot field was required, which included control of an engine failure and completion of terminal area operations with the failed engine. Existing military requirements did not address all of these conditions and situations; therefore, it was necessary to prepare new requirements and modify existing ones for specific AMST application. The general specification for V/STOL Flying Qualities (MIL-F-83300, Reference 2) was not used extensively since the requirements were based mainly upon Vertical Takeoff and Landing (VTOL) flight.

The longitudinal requirements of MIL-F-8785B required the most modification. The short field Operational Flight Envelopes were modified to account for hot day operation (sea level/103°F, an AMST operational requirement), gust encounters and a minimum operational speed based on 1.2 times the stall speed. An AMST must be capable of encountering the same upgusts as encountered by conventional jet transports without stalling. These gusts were defined as 20 knots with all engines operating (AEO), and 15 knots with the critical engine inoperative (CEI), and will provide adequate angle of attack margin. Since a STOL airplane approaches at a lower airspeed than a similar conventional airplane, the angle of attack margin to stall must be larger than that normally provided. The gust magnitude was reduced with an engine failure because the probability of having an engine failure and encountering the higher gust magnitude was considered small.

The stall speed for the landing configuration was based on the following condition that results in the highest stall speed; either AEO at approach power on the engine(s), or CEI with takeoff power on the remaining engine(s). This stall speed would then be the reference used for all thrust settings. Adequate speed and horizontal gust encounter margins were provided by the 1.2 factor times this stall speed. In the event of an engine failure, the speed margin would provide the pilot with time to increase power from approach setting to takeoff power. As can be seen from the figure , the stall speed is a function of thrust setting.



Power settings significantly below that required for approach were experienced during initial intercept of a six degree glide slope from level flight. To insure a safe margin from stall when operating with low power settings, a stall warning system should be utilized.

Two further points are highlighted concerning desired control characteristics as the STOL configuration stall speed is approached. First, a requirement was added that prohibited the airplane from being flown at a speed lower than the minimum air control speed, V_{mc_a} (i.e., the minimum speed at which a dynamic engine failure could be safely controlled). This was different from the requirements of MIL-F-8785B which addresses V_{mc_a} only for the takeoff configuration. For conventional airplanes this is adequate since directional control with an engine failure is the primary concern. However, with the use of powered lift during a STOL landing the rolling moment due to an engine failure becomes significant and a V_{mc_a} concern can exist. Further, at the stall speed the lateral control must be sized to balance the static asymmetric rolling moments due to an engine failure. This requirement is compatible with the added V_{mc_a} requirement in that if one is met the other should be also.

Only two primary longitudinal controllers were permitted to control the airplane, for example, a stick and throttle. The requirement was based on the NASA Ames Research Center studies which found that the pilot workload became unacceptably high if three controllers were used continuously during a STOL landing. A third controller might be used to command flap angle or thrust vector. A controller such as a direct lift switch on the throttle would be acceptable as long as the pilot did not have to remove his hands from the stick or throttles to operate it.

The flying qualities requirements for short landings were written such that either the normal backside control technique (i.e., column for airspeed and thrust for flight path) or the frontside control technique (vice versa) could be used. Use of the frontside control technique on the backside of the power required curve would require automatic commands to control surfaces and thrust to obtain the proper airplane response. Either control technique appeared to be acceptable for flight test pilots in terms of precision of control, training and safety. However, further study is necessary to determine if these results are also valid for low-flight-time pilots, and if pilots using a backside control technique would revert to a frontside control technique during an unexpected, hazardous situation.

For either control technique, it was desired to decouple the airplane response to pilot inputs to the greatest extent possible (i.e., make airspeed and flight path responses independent). For the frontside control technique, a requirement was added that the steady state attitude change to flight path angle change $\frac{\Delta\theta}{\Delta\gamma}$ fall within the following limits:

Level	$\Delta\theta/\Delta\gamma$	
	Min	Max
1	0.75	1.5
2	0.5	1.5

This requirement was based primarily on simulation results (Reference 3), and the intent was to make the STOL airplane respond as if it were operating on the frontside of the power required curve. That is, for a conventional airplane during a climb or descent at constant speed, the angle of attack is essentially constant. Hence, the following derivation indicated that a $\Delta\theta/\Delta\gamma$ of approximately one is required:

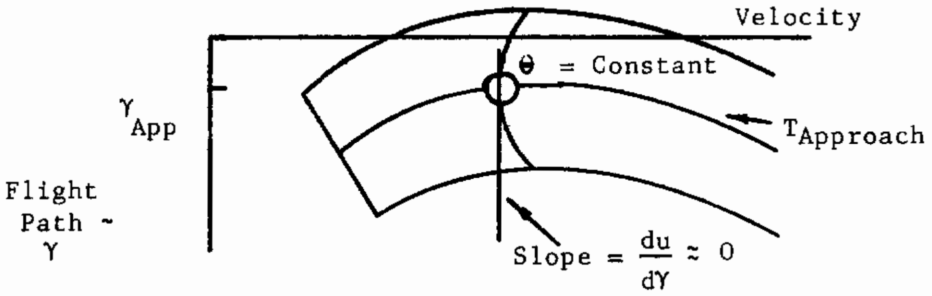
$$\theta = \gamma + \alpha$$

$\frac{\partial\theta}{\partial\gamma} = \frac{\partial\gamma}{\partial\gamma} + \frac{\partial\alpha}{\partial\gamma}$ and since $\frac{\partial\alpha}{\partial\gamma}$ is essentially zero for conventional response:

$$\frac{\partial\theta}{\partial\gamma} = \frac{\partial\gamma}{\partial\gamma} \text{ or } \frac{\Delta\theta}{\Delta\gamma} = 1$$

The requirement implies that automatic commands to control surfaces and thrust are provided in order to obtain the required $\Delta\theta/\Delta\gamma$ on the backside of the power required curve.

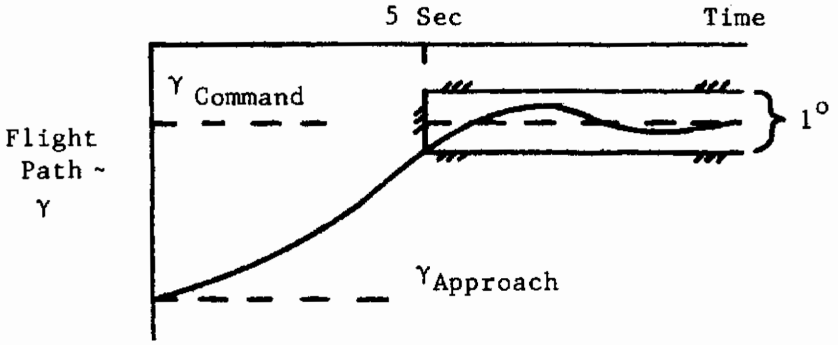
For the backside control technique, the requirement was that the slope of steady state velocity change to flight path angle change ($\Delta u/\Delta\gamma$) be approximately zero when pitch attitude is held constant. This is illustrated on the following figure:



This requirement was based on discussions with NASA Ames. The intent was that thrust changes would result mainly in a flight path response, and not airspeed changes. Sufficient data were not available to specify a quantitative requirement.

Operation on the backside of the power required curve was restricted by limiting the positive values of the slope of flight path angle change to airspeed change $\frac{\Delta\gamma}{\Delta V}$ to values that did not restrict short field performance. NASA Ames had determined that operation on the backside of the power required curve was not a problem as long as sufficient thrust was available for flight path control. However, the USAF was concerned that sufficient thrust would not be available, so operation on the backside of the power required curve was limited by $\Delta\gamma/\Delta V$. The $\Delta\gamma/\Delta V$ requirement does not apply to an airplane that has a speed hold system since ΔV would be essentially zero and the slope then approaches infinity. The $d\gamma/dV$ values of the general MIL-F-8785B were retained for conventional takeoff and landing (i.e., at higher speeds and less flap deflection).

Requirements were added to those of MIL-F-8785B concerning the response of the flight path to a command, and the magnitude of the flight path change required for safe and routine STOL landings. The flight path response requirement is illustrated below.



The requirement was added to ensure that the flight path response to command was rapid and that the flight path change could be maintained. The time of 5 seconds was based on comparison with the B-1 flight path response time during approach, and was also recommended by NASA Ames (Reference 4). The tolerance band of ±0.5 degrees about the steady state value was selected arbitrarily.

Various values for the commanded change in flight path were also defined. An AMST with all engines operating must have the capability to obtain from the initial STOL flight path both level flight or a negative flight path change of 4 degrees. An AMST that sustains an engine failure below the go-around decision height must reach the runway and land in winds up to a 16 knot headwind or 6 knot tailwind. When a landing is made after an engine failure has occurred above the go-around decision height, an AMST must be able to change flight path angle by ±2 degrees in clam air, as well as be able to compensate for 23 knot headwind or 10 knot tailwind.

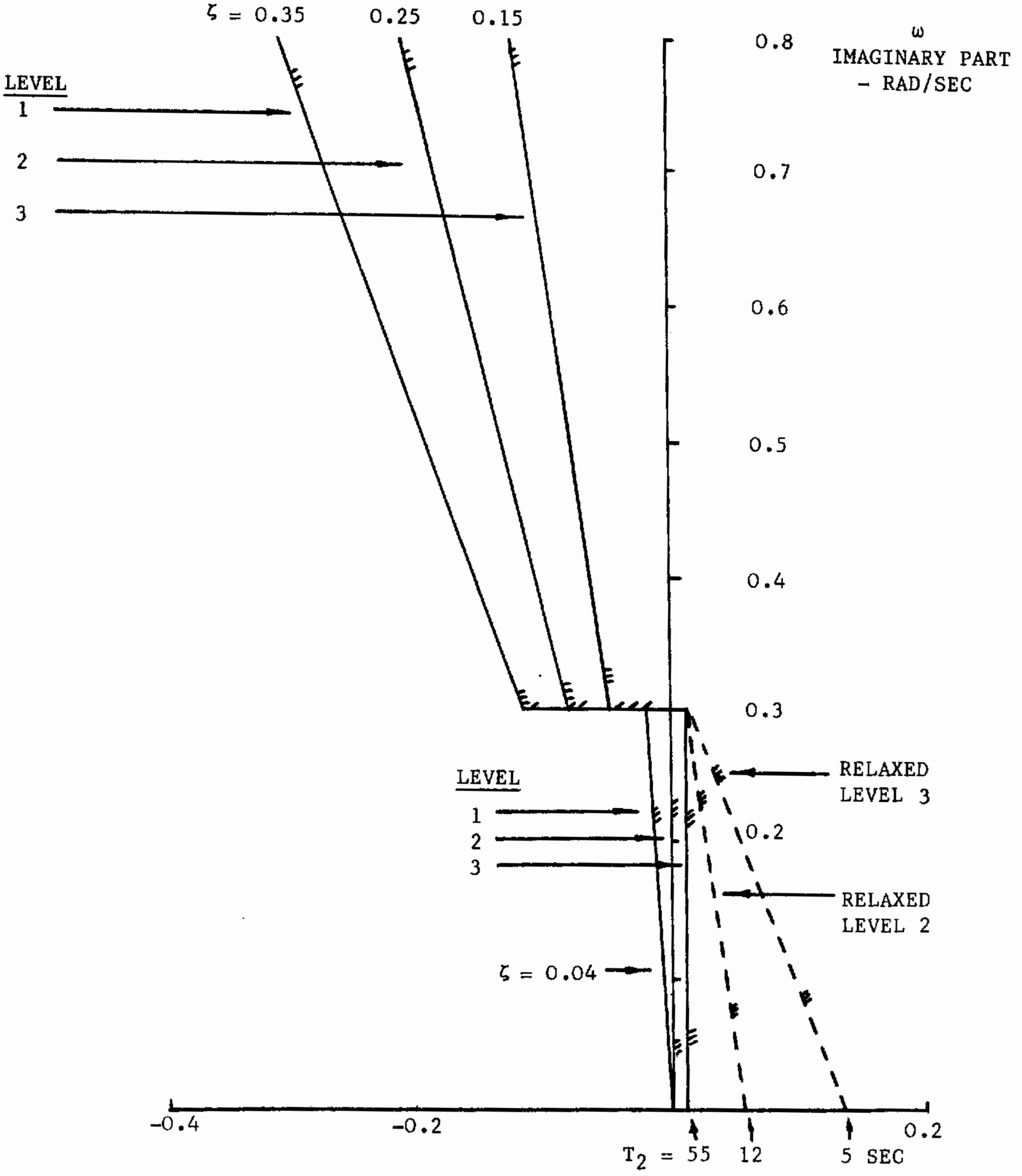
These requirements were added to specify the minimum flight path control required for safe and routine STOL operation. The requirement may have a direct impact on sizing the engines since thrust would be the primary means of controlling the flight path on the backside of the power required curve. For this reason, this requirement was discussed more than all the other changes made to the general MIL-F-8785B and was the most controversial. The basis for the requirement was simulation and flight test studies done by the NASA Ames Research Center (References 4 and 5). Capability to change the flight path was necessary to track to a desired touchdown point and to correct flight path errors due to the pilot, turbulence or wind shears. Three different cases were addressed in the requirement:

All Engines Operating (AEO), and Critical Engine Inoperative (CEI) below and above the engine-out go-around height. The critical case would be the CEI landing where the engine failure occurred above the go-around decision height. Maximum available thrust would be reduced due to the engine failure, and since the probability of this case occurring would be greater than the one where an engine failure occurred below the go-around decision height, higher wind shear magnitudes must be accounted for in the design. The magnitudes defined in the requirement were based on ASD judgment. No manually commanded configuration changes were allowed once the landing approach was begun in order to reduce pilot workload. Further, the configuration change required to optimize flight path change capability would be difficult to determine since it would be a function of the winds or shears encountered. The configuration change would also take time which may not be available when close to the ground. Manual configuration changes would take longer than automatic since, in general, command would be stated verbally by the pilot to the copilot who must then react.

The flight path change of -4 degrees with all engines operating would result in a total flight path angle of -10 degrees for a -6 degrees STOL approach angle. A capability near this magnitude was required for capturing the STOL glide slope from level flight. Negative corrections to the flight path are not as critical as positive corrections since if the pilot cannot correct downward, a go-around could be commanded and safety not compromised. The pilot must make upward corrections or risk short or high sink rate landings. It is strongly recommended that future research be conducted to determine the flight path change capability required for safe STOL landings, particularly because of the significant impact the requirement can have on both engine size and cost.

The frequency and damping requirements of the general MIL-F-8785B were modified to account for STOL unaugmented mode characteristics, as well as for augmented mode characteristics with all systems operational. The lower bounds on the unaugmented short period frequency requirement (Level 3) for the landing flight phase were relaxed if the airplane complied with the flight path dynamic response requirement discussed above. The reason for this was that the frequency requirement was intended to provide a minimum level of load factor or flight path control through the longitudinal controller. Since the thrust is used to control flight path for a STOL airplane it appeared reasonable to relax the frequency requirement if the flight path response due to thrust was acceptable.

The longitudinal damping requirements are shown in Figure 1. The Levels 1, 2, and 3 requirements apply for all categories, and the solid lines on Figure 1 were based on the general MIL-F-8785B (Reference 1). The damped frequency of 0.3 rad/sec was selected based on AMST root location as a reasonable boundary between short



σ, REAL PART ~ RAD/SEC

FIGURE 1. SYSTEM DAMPING

duration and long duration modes. The relaxed regions for Levels 2 and 3 (dashed lines) were based on SST approach simulation study results (References 6 and 7) which indicated safe flying qualities were possible with root locations even more unstable than allowed by Figure 1. Roots may be in the relaxed areas for only short periods of time to prevent high pilot workload or fatigue. These damping requirements were considered adequate for the AMST program since both prototypes had damonstrated good damping characteristics. Further study is required to develop a general longitudinal damping requirement that addresses all system modes in a systematic and nonsubjective fashion.

In general, the lateral-directional requirements of the general MIL-F-8785B were used for the AMST. Several notable exceptions are discussed below. The AMST Level 1 roll control capability for Category A tasks was relaxed from the general MIL-F-8785B heavy airplane (Class III) requirement of 30 degrees bank angle in 1.5 seconds to 30 degrees in 2.0 seconds. The AMST Level 1 requirement was based on AMST demonstrated capability, which was found to be acceptable during STOL operation with an engine failed, MAC tactical maneuvers, in turbulence, crosswinds and in formation flight. The roll requirements must be met at the minimum operational speed of 1.4 V_s for Categories A and B (aerial delivery excluded), and 1.2 V_s for Category C (including aerial delivery).

A capability to land in a crosswind of 30 knots, measured at 50 feet altitude, was required at the short field approach speeds. Specifying the altitude at which the crosswind was measured was necessary since the new turbulence model in the AMST requirements accounted for wind shear. A crosswind of 30 knots at the STOL landing speeds resulted in a sideslip angle near 20 degrees. This may be the critical design case for rudder sizing, and selection of the vertical tail airfoil to avoid fin stall.

The minimum ground control speed, V_{mc_g}, the speed during takeoff at which an engine failure can occur and the pilot can keep the airplane on the runway during a continued takeoff, must be based on the narrow STOL field width of 60 feet. This meant that lateral deviations from the runway centerline had to be less than 20 feet to keep the main landing gear on the runway. This was a necessary requirement for safe operation, but it could significantly affect tail size, hydraulic sizing for high rudder rates or flight control yaw damper logic depending upon how fast a pilot can be expected to react. Since the pilot reaction time is an integral part in determining V_{mc_g}, the airplane design to yield low V_{mc_g} values can become quite subjective since pilot reaction time can vary from zero to several seconds, depending upon pilot anticipation and cues.

As mentioned above, the atmospheric model for the AMST specification was different from the general MIL-F-8785B. STOL airplanes flying on the backside of the power required curve and lower approach speeds are more susceptible to changes in flight path, angle of attack and airspeed when gusts and shears are encountered. Thus, it was necessary to model the gusts and shear characteristics accurately to determine actual STOL capability. The AMST model was a simplified version of the model developed for the Federal Aviation Administration for flight certification of airplanes by simulation (Reference 8).

In conclusion, this paper has addressed some of the changes made to the general MIL-F-8785B for the AMST. A more complete discussion of this topic is presented in "USAF Flying Qualities Requirements for a STOL Transport" (ASD-TR-78-13).

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Dwight Schaeffer, Boeing: Why are the $\partial\gamma/\partial V$ required for CTOL much more stringent than the STOL requirements?
Answer: The $\partial\gamma/\partial V$ requirements for CTOL are more stringent since pilots trained only in CTOL flight requiring front side of the power required curve piloting technique must be restricted from operation very far back on the power required curve so that the front side technique still works well.

Frank Wilson, Lockheed-Georgia: C-130 STOL flight simulation in the presence of wind shear showed that powered lift aircraft tend to be much more tolerant of wind shear than do others such as the C-141 or C-5. Reason is that power advance for go-around provides DLC simultaneously with longitudinal acceleration which greatly minimizes altitude loss.
Answer: In general, it is felt that STOL airplanes are more susceptible to changes in angle of attack, airspeed and altitude when shears are encountered than conventional airplanes. Results of C-130 STOL flight simulation are directly related to shears encountered and speed of approach.