AIAA 79-1680R

Effect of Reduced Visibility on VTOL Handling Quality and Display Requirements

Roger H. Hoh* and Irving L. Ashkenas†
Systems Technology, Inc., Hawthorne, Calif.

Available data have been used to quantify the intuitive idea that acceptable levels of pilot workload (Cooper-Harper ratings and commentary) for the low-speed and hover task are dependent on outside visibility level, augmentation, and cockpit displays. An outside visual cue scale is developed to quantify the environmental conditions for the intended mission in a more fine-grained manner than simply specifying visual meteorological conditions or instrument meteorological conditions. A tentative handling quality criterion for low speed and hover is developed in terms of augmentation, outside visual cue level, and cockpit display sophistication. In general, the criterion indicates that rate augmentation in acceptable only in good visibility. Low speed and hover in degraded levels of visibility require attitude augmentation which must be upgraded to a translational rate command system in zero visibility. Finally, there is evidence that the most critical flight phase may be final deceleration to hover as opposed to steady hovering.

Nomenclature

K_p	= pilot gain between stick and perceived attitude error
K/s	= refers to shape of frequency response being -20 dB per decade with a phase angle of -90 deg
K_x	= pilot's internally generated position feedback gain (see Fig. 2)
$K_{\dot{x}}$	= pilot's internally generated velocity feedback gain (see Fig. 2)
M_δ	= pitch acceleration per unit control input
s	= Laplace operator
T_{θ_1}	= numerator zero of hover transfer function (see Fig. 1)
x	= position with respect to hover reference point
$\dot{x}$	= linear velocity with respect to hover reference point
Y_c	= vehicle transfer function
Y_p, Y_{p_θ}	= quasilinear pilot model relating perceived errors to cockpit control motions
δ	= cockpit control motion
ζ	= damping ratio of imaginary root of characteristic equation (see Fig. 1)
θ	= pitch attitude
λ	= real root in characteristic equation (see Fig. 1)
ω	= frequency of imaginary root of characteristic equation (see Fig. 1)
$(\ )'$	= attitude loop has been closed
$(\ )''$	= attitude loop as well as translational velocity loop has been closed (see Fig. 2)

Introduction

THE motivation for the present work stems from increasing projected requirements to operate military VTOL's in reduced visibility conditions in low speed and hover. In particular, it is oriented toward upgrading the military flying quality specification (MIL-F-83300). However, the results are equally applicable to civilian operations and should be of value for providing the necessary data for developing civilian airworthiness criteria.

Available data and experience have been used to quantify the intuitive idea that the minimum acceptable handling qualities for low speed and hover are strongly dependent on the visibility level and available displays. In this regard, the tentative criteria (minimum level of controls or displays) are presented in terms of a visibility scale which quantifies the environmental conditions for the intended mission in a more fine-grained manner than simply specifying instrument meteorological conditions (IMC) or visual meteorological conditions (VMC).

The ultimate benefit of this research is expected to be twofold: 1) it provides a set of tentative flying quality boundaries which can be used either as design goals or to shape preliminary certification standards for IMC VTOL operation; and 2) it puts the present data base in a format where its shortcomings, including gaps in coverage, are more recognizable. This latter consideration can and should lead to increasingly productive experimental programs which maximize the benefit of past work and are conducted with clearly defined objectives oriented toward filling the specific data requirements defined herein.

Outside Visual Cues

Most of the available data for low-speed and hover handling criteria has been obtained with good visual outside references and with no requirement for unattended operation. The real-life existence of secondary tasks, and intermittent to total loss of visual references, places increased demands on the pilot—an effect which is not discernible from such data. For example, pilot ratings for an unaugmented helicopter[1] and a highly augmented translational rate command (TRC) system[2] all fall within the acceptable region (pilot rating better than 3.5). This result is a consequence of experimental scenarios which tend to be tailored toward the systems being investigated. That is, with pure rate systems the scenario is usually benign, thereby usually allowing intense, full-time attention; whereas with a translational rate command system, the task tends to be more demanding. The most critical contributor to the total pilot workload appears to be the quality of out-the-window cues for detecting aircraft attitudes, and, to a lesser extent, position and velocity. Currently, these cues are categorized in a very gross way by designating the environment as either VMC or IMC. A more

Presented as Paper 79-1680 at the AIAA Atmospheric Flight Mechanics Conference, Boulder, Colo., Aug. 6-8, 1979; submitted Nov. 1, 1979; revision received June 6, 1980.

*Senior Research Engineer. Member AIAA.
†Vice President. Fellow AIAA.

discriminating approach is to classify visibility in terms of the detailed attitude and position cues available during the experiment (or proposed mission), and to associate handling qualities requirements with these finer-grained classifications.

In the remainder of this paper, existing data are utilized to make preliminary estimates of the equivalent low-order system hover dynamics required to cope with various classifications or levels of the operating environment. These estimates are based on a combination of closed-loop analyses and pilot commentary from flight and simulator experiments. The results are presented in terms of the specific levels of the maximum acceptable outside visual cues (OVC) (worst visibility) for each type of equivalent system response and display sophistication.

Development of Outside Visual Cue Scale

The longitudinal pilot/vehicle closure characteristics for different levels of augmentation for hover position control and speed control are shown in Fig. 1. The comments below each root locus sketch indicate the required pilot workload function and OVC's to maintain adequate stability margins and path mode bandwidth (performance).

In the case of the rate augmented systems, it can be seen that the pilot must close the attitude loop with a reasonably high gain to stabilize the phugoid mode and to drive ω' into a favorable region as necessary for a good outer path loop closure. The requirement for a high-gain closure implies a need for high pilot scanning activity.[3] In addition to a high-gain attitude closure, the pilot must also develop lead on his position error to maintain path stability. Figure 1 indicates that a reduction in workload would be expected with attitude augmentation due to the elimination of the need for the pilot to perceive, stabilize, and constrain the pitch and roll attitudes. The degree of workload reduction will of course depend on the attitude stability augmentation system bandwidth and damping. Finally, with a TRC system, the pilot simply has to perceive and feed back the position loop without equalization, i.e., the requirements for attitude stabilization and velocity feedback have been eliminated. The need for certain specific outside visual cues has been inferred from such closed-loop considerations; further; these OVC levels have been logically quantified in terms of a scale as shown in Fig. 2a. Certain specific closed-loop considerations, which were considered in formulating the scale, are summarized below and by the generic closed-loop structure in Fig. 2b.

1) A requirement for closure of the attitude loop implies VMC conditions must prevail for adequate control.

2) If the equivalent system dynamics require closure of position and position rate, but not attitude, a minimum set of operating conditions quantified as OVC = 3 is defined.

3) OVC = 4 quantifies the operating condition where velocity and attitude cues are not available; that is, only the outer loop in Fig. 2b can be closed by the pilot.

4) OVC = 5 indicates that no outside visual cues are available.

Control/Display Tradeoffs

Pilot workload can also be reduced via improved displays. Recent work in the control/display tradeoff area includes the Calspan X-22 flight tests[4] and the CH-46 variable-stability helicopter.[5]

Results of the X-22 experiment are summarized in Fig. 3.[4] These data represent a deceleration to hover using manual rotation of the thrust vector in IMC conditions (OVC = 5 in Fig. 2). The ratings reported[6] were made by one pilot, although other pilots flew and rated some of the configurations. Perhaps the most significant result of these data is that increased augmentation is considerably more beneficial

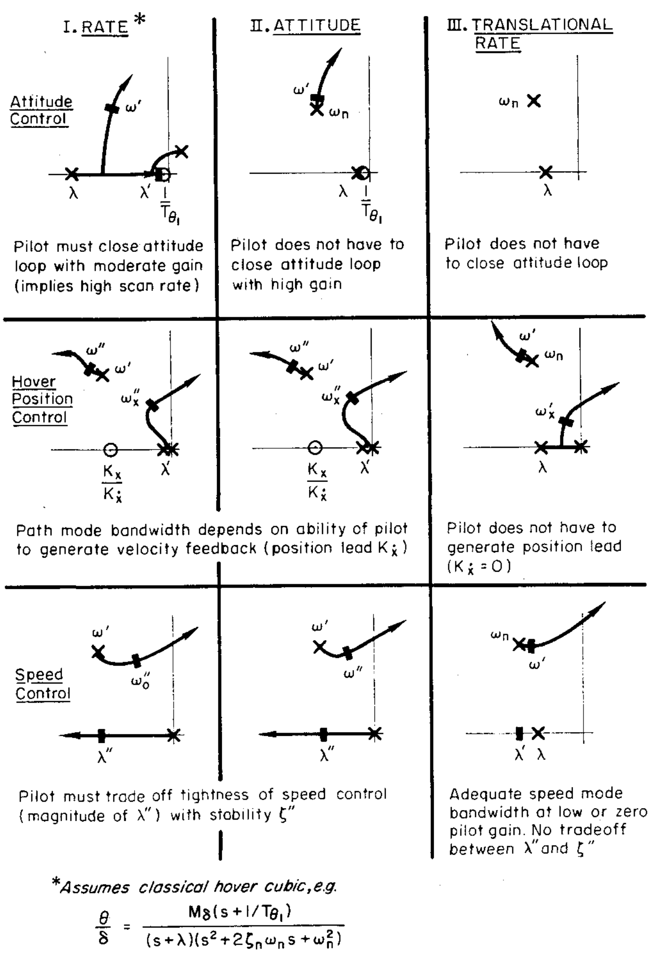
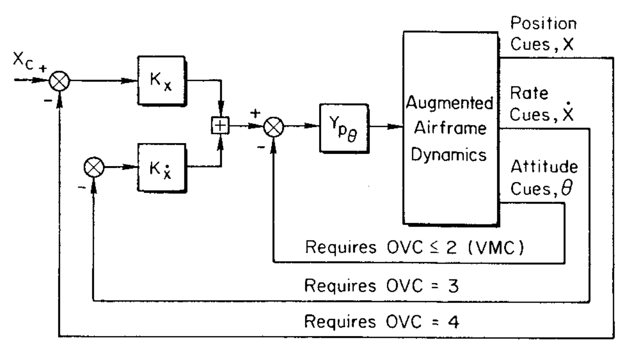


Fig. 1 Pilot loop closure characteristics.

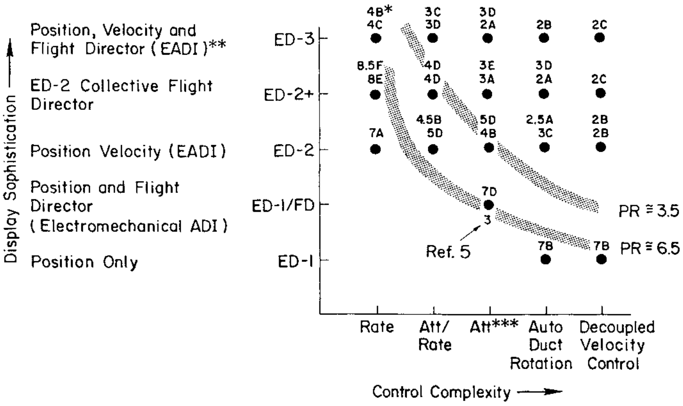
	Attitude Cues	Position and Velocity Cues	OVC Level
	Easily obtained.	Easily obtained.	①
VMC	Somewhat obscured. Requires full concentration to obtain continuous attitude information	Easily obtained	②
Partial IMC	Inadequate in some sectors of the visual field.	Adequate position. Marginal rate cues.	③
Partial IMC	Inadequate over most of visual field.	Position and rate cues are marginal. Rate cues are intermittently unavailable.	④
IMC	Not available.	Not available.	⑤

a) Quantification of outside visual cues



b) Required outside visual cues for control

Fig. 2 Development of outside visual cue scale.



*Numbers are Cooper-Harper pilot ratings, letters are turbulence effect ratings. Two ratings indicates two separate evaluations of a configuration.

**EADI ⇒ electronic attitude director indicator on an integrated display on a CRT.

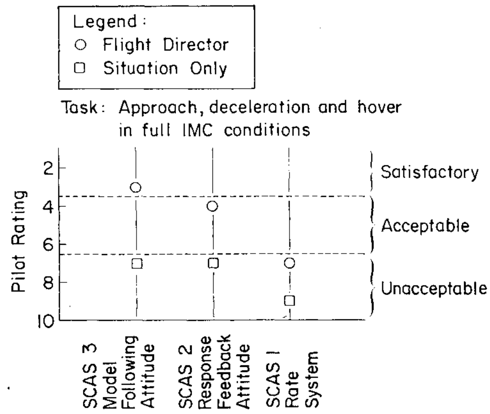
***Att refers to a model following attitude system with an inner loop bandwidth of 4 rad/sec.

HOVER DYNAMICS

	θ/δ	ϕ/δ
Rate	$\frac{K(0)}{(2.94)[.10,.41]}$	$\frac{K(0)}{(2.71)[-.025,.45]}$
Att/Rate	$\frac{K}{[.7,2.0]}$	$\frac{K(2)}{(0)[.52,2.15]}$
Att	$\frac{K}{[.7,2.0]}$	$\frac{K}{[.7,2.0]}$

Note: $(1/T) \Rightarrow (s+1/T)$ $[\zeta,\omega] \Rightarrow s^2+2\zeta\omega s+\omega^2$

Fig. 3 Pilot rating data for primary matrix (X-22 experiment[4]).



HOVER DYNAMICS

	θ/δ	ϕ/δ
SCAS No. 1 (Rate)	$\frac{K(.094)}{(2.67)[0,.27]}$	$\frac{K(.29)}{(2.27)[.051,.37]}$
SCAS No. 2 (Response Feedback)	$\frac{.2}{[.79,1.62]}$	$\frac{.2}{[.88,1.10]}$
SCAS No. 3 (Model Following)	$\frac{.2}{[.75,1.41]}$	$\frac{.2}{[.75,1.41]}$

Fig. 4 Results of CH-47 variable-stability helicopter control/display experiment.[5]

than improved displays. This conclusion is somewhat compromised by the pilot rating of 7 for the mechanical flight director (configuration ED-1/FD). It should be noted however, that the very poor rating given to ED-1/FD in Fig. 3 is not consistent with the satisfactory pilot rating (PR = 3) given to SCAS No. 3 in Fig. 4. This apparent discrepancy is probably due to the more complex deceleration maneuver in the X-22 (manual duct rotation) when compared to the CH-46 (constant attitude). The complexity of the control usage required to decelerate is shown to be critical later in this paper (see "Pilot Workload"). The improved rating,[5] when plotted on Fig. 3, tends to support the contention that displays have a significantly less-dominant effect than augmentation on pilot workload reduction.

A dramatic improvement in pilot opinion is shown in Fig. 3 (for IMC tasks) when upgrading from a rate system to an attitude system. This is supported by the results of the variable stability CH-47 helicopter[5] (as shown in Fig. 4). The task on this latter experiment was an instrument landing system (ILS) approach to hover with an electromechanical flight director.

Unfortunately, the rate stability augmentation system (SAS) had a divergent mode above 40 knots (Ref. 5) ($\lambda = -0.26$) and no pilot rating data were taken for low speed and hover per se. However, there was evidence from the pilot commentary that the rate SAS was unacceptable even below 40 knots (where the pitch divergence disappears). It was noted that "even though decelerations to hover could be consistently achieved with the rate SAS and flight director configuration, the pilot workload was considered to be unacceptably high." Thus, there is strong evidence that even with a good rate SAS and a flight director, the low-speed and hover handling qualities are unacceptable for IMC (OVC = 5).

Additional evidence that rate-like attitude response characteristics are unacceptable for low-speed flight in IMC, conditions may be found in the results of an instrument flight evaluation of the OH-6A helicopter. The following quote is taken from Ref. 7:

> "Associated with instrument flight are additional tasks of tuning radios, examining flight charts and approach plates, and various other required tasks. Accomplishment of these tasks requires the removal of the pilot's hands from at least one of the flight controls. Flight in instrument conditions requires total concentration with constant corrective control inputs just to maintain a trim condition. A copilot would therefore be required to aid the pilot in performing IFR operations if IFR flight were attempted."

The pilot/vehicle closure characteristics of the OH-6A are given in Fig. 5 (Ref. 7) for speeds from hover to 40 knots. Utilizing the pilot model rules as stated by McRuer and Krendel,[3] the required compensation is seen to be a lead at 0.5 s in order to equalize to a K/s. Such compensation is expected to produce only moderate penalties in pilot opinion, yet the pilot comments indicated 100% workload was required simply to maintain control in IMC conditions (pilot ratings of 6 to 7).

Based on the preceding evidence, it seems reasonable to conclude that rate-like attitude systems are acceptable for low speed and hover only in VMC conditions.

Figure 4 indicates that a rate SAS combined with an electromechanical flight director results in level 3 flying qualities (PR = 7). However, the data described by Lebacqz and Aiken[4] indicate that rate augmentation may be suitable for backup systems (level 2) in an electronic display which integrates position, velocity, and flight director commands (ED-3 in Fig. 3).

Rate command/attitude hold (RCAH) systems result in considerably improved pilot ratings over pure rate systems—a fact which stems from the disturbance regulation characteristics inherent to this type of system. There are very little data on RCAH systems for low speed and hover. One exception is a fixed-base simulation which was run to evaluate a system design to allow ILS (OVC = 5) approaches to hover

Table 1 Pilot ratings and commentary for rate command/attitude hold system in IMC conditions

Pilot task	Pilot rating	Comments
Constant speed glide slope tracking	2 FD[a] 2 AP[b]	Longitudinal and lateral flight directors easy to track. Workload is low.
Deceleration to hover (IMC)	4½ FD 2 AP	Constant attention required to keep flight director centered. Kind of wanders during deceleration, cannot set and forget.
Hover (IMC) and vertical descent	4-½ to 5 FD 2 AP	1) Very little change in attitude results in pitch bar movement. Requires light touch on stick to keep from overcontrolling. Not unsafe. 2) Requires constant attention. Need time to scan other instruments (besides flight director) this close to ground.

[a] FD = Pilot flying via longitudinal and lateral flight director bars. Collective is automatic.
[b] AP = Fully automatic to touchdown.

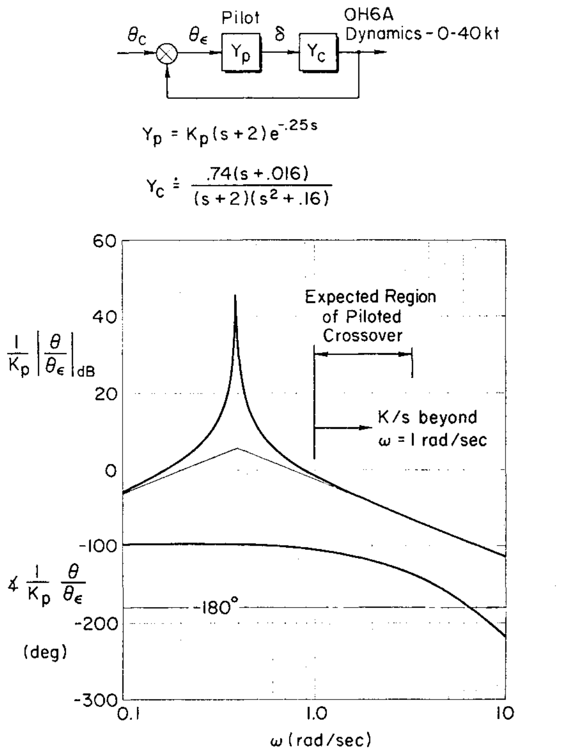


Fig. 5 Piloted attitude control characteristics of OH-6A for hover to 40 knots.

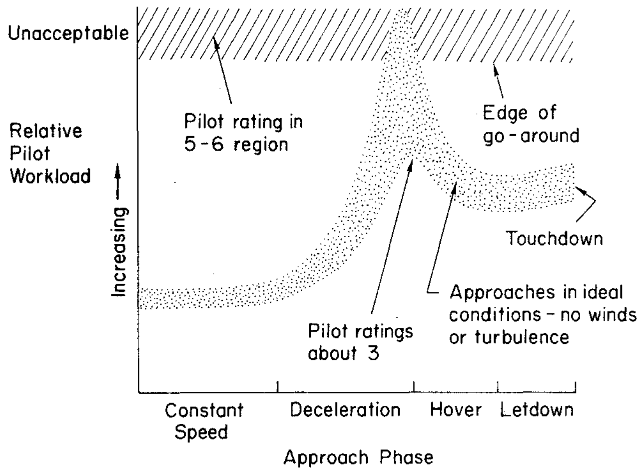


Fig. 6 Relative pilot workload as function of approach phase.

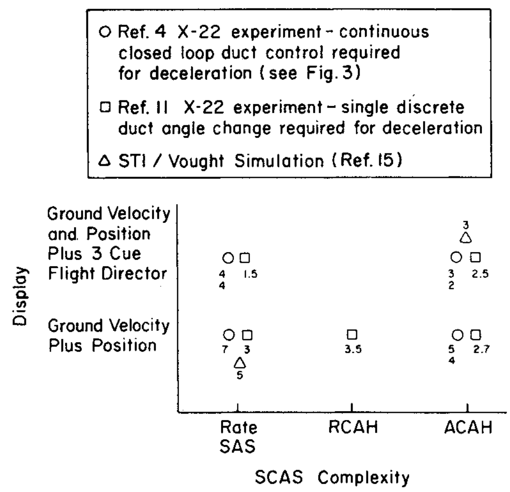


Fig. 7 Comparison of pilot ratings for similar controls and displays but different deceleration profiles.

and vertical letdown for the XV-15 Tilt Rotor.[8] The final manual system included a mechanical flight director plus moving map display and a fully automatic collective axis to keep pilot workload at a reasonable level. A constant attitude deceleration law was incorporated in the flight director—also, to keep pilot workload at a reasonable level. A fully automatic system was also configured. The pilot ratings and commentary are summarized in Table 1. These data indicate that an RCAH system with a mechanical flight director is not satisfactory for low speed and hover in IMC (OVC = 5) conditions.

Pilot Workload

There is some evidence that the highest pilot workload occurs not during hover but during the final phase of deceleration. For example, the initial CH-46 results[9] indicated operationally unacceptable pilot workload, whereas the latest experiments[5] resulted in a pilot rating of 3 with essentially the same controlled element and displays. The early experiment[9] utilized a more complex pitch profile than the latest experiment[5] which allowed deceleration at constant attitude. A mission-phase dependency of pilot workload is specifically indicated by Kelly et al.,[10] where an approximate variation in pilot rating with approach phase was shown (see Fig. 6). This plot was formulated on the basis of data obtained from the collective experience gained in the CH-46/47 experiments conducted from 1962 through 1977.[5,9] The comments on the plot reflect informal discussions with the authors.

Additional support to the hypothesis that the deceleration phase is critical stems from the apparent discrepancy in the two X-22 experiment reports described by Lebacqz et al.[4,11] These data are compared directly in Fig. 7, where it is shown that a drastic improvement occurred in the later experiment.[11]

Table 2 Maximum allowable OVC levels for each category of equivalent system response

Lower-order equivalent system type	Flying quality level	Pilot display: Raw data	Mechanical flight director	Integrated display-flight director plus aircraft velocity information
Rate	Level 1	1	2	3
	Level 2	2	4	5
Rate command/ attitude hold	Level 1	2	3	3
	Level 2	2	5	5
Attitude (response feedback)	Level 1	2	3	3
	Level 2	2	5	5
Attitude (model following)	Level 1	2	4	4
	Level 2	2	5	5
Translational rate with attitude	Level 1	3	5	5
	Level 2	3	5	5
Translational rate with direct force control	Level 1	3	5	5
	Level 2	3	5	5

Comparison between the experiments reveals that two primary differences existed: 1) the display was projected on the windscreen (i.e., a HUD) in the second experiment; and 2) a much simpler deceleration control usage was required. The evaluation pilot's view of the outside world was blocked so that any benefits that might have accrued from the HUD were lost, i.e., the situation was essentially head down. This leaves the simpler deceleration profile (i.e., one discrete duct angle controller change vs continuous pilot closed-loop control of duct angle) as the most viable explanation of the difference in ratings. Other differences, which are felt to be relatively insignificant, were in the baseline vehicle (X-22[4] vs AV-8B[11], both rate-augmented), in the pitch and roll attitude displays, and in the directional SAS (augmented yaw damping vs selectable turn coordination, heading hold).

Clearly, more experimental data are required to fully understand such effects. However, there is considerable evidence which indicates that the minimum acceptable control/display combinations are strongly dependent on the final deceleration characteristics of the configuration.

Results and Supporting Rationale

The following paragraphs summarize the rationale used to interpret the foregoing data and to finally arrive at the tentative allowable visual cue levels presented in Table 2 for each type of equivalent system form and display.

Rate Systems

All of the evidence indicates that rate systems with raw data displays are acceptable for VMC flight only (OVC = 1). The addition of a mechanical flight director does not move the ratings out of the unacceptable range for full IMC (Fig. 4). However, there is sufficient anecdotal evidence to indicate that an increase to an OVC level of 2 is warranted. The high-pilot workload associated with rate systems (Figs. 1 and 2) precludes the normal allowance of partial IMC even with a flight director, as confirmed by the pilot rating of 7 in Fig. 4. When used as an emergency backup though, partial IMC to an OVC level of 4 seems indicated by pilot commentary, showing that deceleration to hover could be accomplished even though the workload was extreme.

Figure 3 indicates that a fully integrated display results in a pilot rating of 4 for an approach in OVC level 5 conditions (full IMC). Again, because of the high scanning workload associated with rate systems, we have elected to tentatively restrict the allowable operating environment to 3 (see Table 2), even with the addition of a fully integrated display. This is increased to an OVC level of 5 when utilized as a backup system (level 2 flying qualities), based primarily on the pilot rating of 4 in Fig. 3.

Attitude Systems

Figure 4 indicates that response feedback and model-following attitude systems are unacceptable if only raw data displays are available. Therefore, an OVC level of 2 is specified in Table 2. There is considerable discrepancy between the X-22 results stated by Lebacqz and Aiken[4] and the CH-46 results described by Niessen et al.,[5] regarding attitude systems with a mechanical flight director (PR = 7 vs PR = 3, respectively). Until further data are available, we have elected to compromise by allowing OVC level 3 conditions for response feedback systems and OVC level 4 conditions for model followers when the display consists of a mechanical flight director. The increase to OVC level 4 for model following is based on the improvement indicated in Fig. 4 (pilot rating improves from 4 to 3) and on the obvious benefits which accrue from the gust regulation characteristics of a model-following system. Both the response feedback and model-following attitude systems should be adequate as a backup mode for full IMC conditions; therefore, an OVC level of 5 is indicated in Table 2 for level 2 flying qualities (for a mechanical flight director). The only reservation is the pilot rating of 7 (ED-1/FD) in Fig. 4. However, the pilot ratings of 3 and 4 in Fig. 4 are felt to carry enough weight to allow these systems for full IMC conditions, at least for level 2 flying qualities.

The X-22 data in Fig. 3 indicate that a model-following attitude system with a fully integrated display results in pilot ratings in the satisfactory range (PR = 2-3). However, there are some unpublished data from visiting V/STOL pilots who gave ratings from 4 to 7 for even the best configurations in Fig. 3. These pilots were probably not high on the learning curve and did not have the benefit of the primary X-22 evaluation pilot in terms of comparing the best systems with the less desirable rate systems. However, because of the critical nature of hovering in IMC, a conservative approach seems warranted. Therefore, until more experience is gained (e.g., more pilots with adequate evaluation time), it was decided to restrict the response feedback system to OVC = 3 and the model follower to OVC = 4. This may be unduly restrictive and should be subjected to flight testing for validation.

TRC Systems

The translational rate command systems represent a significant decrease in pilot workload according to the analysis summarized in Fig. 1. There are some experimental results[12,13] which support the analysis, but neither reference specifically addresses the IMC hover task. Additionally, there are some fixed-base simulation results which indicate that a TRC system will be satisfactory for IMC hover.[3,13] Based on these results, it seems reasonable to allow light IMC

(OVC = 3) even with raw data. Considering the minimal pilot workload to hold speed or position (see Fig. 1) with a TRC system, an OVC rating of 5 (full IMC) is allowed for the mechanical flight director or the integrated display. It is important to note however that a primary benefit of TRC systems is their ability to hold zero velocity when the pilot releases the cockpit control.[14] Hence the translational rate feedback must be referenced to the desired hover point. Any requirement for the pilot to bias out drift errors makes the workload equivalent to an attitude system.

Conclusions

Based on existing data, a first-cut attempt at establishing minimum acceptable systems for operations in specified levels of visibility has been accomplished. Indications are that rate augmentation is acceptable for visual meteorological conditions only and that a TRC system will probably be required for hovering in full-instrument meteorological conditions.

There is evidence that the final phase of deceleration constitutes the most critical flight condition. Further experiments should concentrate on this area.

There is a substantial amount of disagreement within and among the experiments regarding the minimum acceptable controls and displays. These disagreements result in specific requirements for further experiments.

Finally, most of the existing data indicate that advanced displays are not a substitute for augmentation.

References

[1] Seckel, E., Traybar, J.J., and Miller, G.E., "Longitudinal Handling Qualities for Hovering," Princeton University, Dept. of Aero. Eng., Rept. 594, Dec. 1961.

[2] Bryant, W.B., Cattel, J.C., Russell, W.A., and Trueblood, R.B., "VTOL Advanced Flight Control System Studies for All-Weather Flight. Vol. I: Task I Report," USAAMRDL-TR-75-13A, July 1975.

[3] McRuer, D.T. and Krendel, E.S., "Mathematical Models of Human Pilot Behavior," AGARD-AG-188, Jan. 1974.

[4] Lebacqz, J.V. and Aiken, E.W., "A Flight Investigation of Control, Display, and Guidance Requirements for Decelerating Descending VTOL Instrument Transitions Using the X-22A Variable Stability Aircraft. Vol. I: Technical Discussion and Results," Calspan Corp., Buffalo, N.Y., Rept. AK-5336-F-1, Sept. 1975.

[5] Niessen, F.R., Kelly, J.R., Garren, J.F., et al., "The Effect of Variations in Controls and Displays on Helicopter Instrument Approach Capability," NASA TN D-8385, Feb. 1977.

[6] Lebacqz, J.V. and Aiken, E.W., "A Flight Investigation of Control Display, and Guidance Requirements for Decelerating Descending VTOL Instrument Transitions Using the X-22A Variable Stability Aircraft. Vol.: II Background Information and Supporting Data," Calspan Corp., Buffalo, N.Y., Rept. AK-5336-F-1, Vol. II, Sept. 1975.

[7] Winn, A.L., Griffith, W.E. II, and Mittag, C.F., "Instrument Flight Evaluation, OH-6A Helicopter, Part 1," USAASTA Project No. 72-06, Nov. 1973.

[8] Hofmann, L.G., Hoh, R.H., Jewell, W.F., et al., "Development of Automatic and Manual Flight Director Landing Systems for the XV-15 Tilt Rotor Aircraft in Helicopter Mode," NASA CR-152040, Jan. 1978.

[9] Kelly, J.R., Niessen, F.R., Thibodeaux, J.J., et al., "Flight Investigation of Manual and Automatic VTOL Decelerating Instrument Approaches and Landings," NASA TN D-7524, July 1974.

[10] Kelly, J. R., Niessen, F.R., Yenni, K.R., and Person, L.H., Jr., "Flight Investigation of a Vertical-Velocity Command System for VTOL Aircraft," NASA TN D-8480, July 1977.

[11] Lebacqz, J.V. and Radford, R.C., "An Experimental Investigation of Control-Display Requirements for a Jet-Lift VTOL Aircraft in the Terminal Area," *Proceedings of the AIAA Atmospheric Flight Mechanics Conference,* Palo Alto, Calif., Aug. 1978, pp. 243-252.

[12] Bryant, W. B., Cattel, J.C., Russell, W.A., and Trueblood, R.B., "VTOL Advanced Flight Control System Studies for All-Weather Flight. Vol. II: Task III Report," USAAMRDL-TR-75-13B, July 1975.

[13] David, J., Garnett, T., and Gaul, J., "Heavy Lift Helicopter Flight Control System. Vol. III: Automatic Flight Control System Development and Feasibility Demonstration," USAAMRDL-TR-77-40C, Sept. 1977.

[14] Hoh, R.H. and Ashkenas, I.L., "Development of VTOL Flying Qualities Criteria for Low Speed and Hover," NADC-77052-30, Sept. 1979.

[15] Stapleford, R.L., Clement, W.F., Heffley, R.K., and Fortenbaugh, R.L., "Flight Control/Flying Qualities Investigation for Lift/Cruise Fan V/STOL: Vol. II—Piloted Simulation," Systems Technology, Inc., TR-1122-1, Aug. 1979.