COCKPIT INTEGRATION
FROM A PILOT'S POINT OF VIEW

David L. Green
Vice President

PACER Systems, Inc.
Arlington, Virginia

Abstract

Extensive experience in both operational and engineering test flight is used to suggest straightforward changes to helicopter cockpit and control system design that would improve pilot performance in marginal and instrument flight conditions. Basic differences from airplane fight characteristics justify distinct treatment of helicopter cockpit flight control configurations. Helicopter use of collective for direct lift control and collective to yaw coupling are emphasized in drawing these distinctions. Need for good downward peripheral visibility and truly horizontal glare shield profile are cited for natural visual cues during marginal VMC and approach transition. Needed control system improvements include: 1) separation of yaw from cyclic force trim; 2) pedal force proportional to displacement rate; and 3) integration of engine controls in collective stick. Needed display improvements include: 1) natural cuing of yaw rate in attitude indicator; 2) collective position indication and radar altimeter placed within primary scan; and 3) omnidirectional display of full range airspeed data.

Introduction

The helicopter has one very unique capability, the ability to hover efficiently and precisely for extended periods. And when compared to the airplane, it has the advantage of being able to fly into confined areas, hover, and land vertically without any concern for the stall-spin phenomena.

The trained pilot has no problem exploiting the capabilities of a helicopter during VMC, but when the task is proposed in the IMC environment, the pilot often appears to fall short. This same trend in performance also exists during marginal VMC and during transition from IMC to VMC for landing. That is, the pilot-machine combination is less capable when external visual cuing is marginal or non-existent.

Some of the reasons for this degraded capability are readily apparent when IMC operations are studied. Navigation must be conducted via reference to electronic aids and this means a new level of air traffic control is required, with a concomitant increase in the time consumed by radio communications. These procedural changes increase cockpit workload and reduce the time available for flight control. With less time available to allocate to flight control and dramatically degraded visual cues, the pilot flies with less vigor. Everything happens a bit slower, while the pilot tries to fly with greater precision.

One obvious solution to the IMC case is to incorporate sensor-display concepts which return the real world visual cues to the cockpit (FLIR). Under certain circumstances today's technology makes this type of visual augmentation possible, but even the best of these concepts still have serious shortcomings in truly bad weather. In any event, this type of visual augmentation is considered heroic for many military applications and all civil applications.

From a pilot's perspective, this inability to fully exploit the unique capabilities of the helicopter is a problem which is common to helicopters of all manufacturers. That is, there are a number of common man-machine interface characteristics, which as they stand, detract from the pilot's ability to accomplish the piloting task. And although pilots may desire change, they aren't always able to articulate a winning argument for the features they feel they need. They may not even understand the source problems they are experiencing. So without such convincing argument, many worthwhile improvements go unidentified or deferred.

What follows then are observations, explanations, and suggested requirements for change which do not require heroic efforts. These comments are principally based upon the author's personal experience and observations as an operational helicopter pilot, an engineering test pilot, a research pilot, an experimental test pilot, and a flight test engineer. The intent is to provide insight into the factors which may be confusing to non-pilots and revisit a number of helicopter cockpit design features which have suffered at the hands of the "accepted convention".

The scope of this paper will not allow an in depth treatment of all applicable characteristics which are candidates for change. Nor is it possible to consider all phases of flight, or helicopter applications. Instead, this effort is generally focused on the high workload or high stress situations where pilots are routinely unable to accomplish the transition to hover, or to conduct other slow speed tasks safely. The purpose of the paper is to persuade the reader that there are many reasons to revisit cockpit design and question the conventional wisdom which has been handed down for generations. The premise is that given a bit more design consideration, a helicopter pilot can generally achieve more than is currently expected of him. He cannot only achieve more, he can do it more safely.

The Cockpit

But before we deal with the tough questions related to IMC flight, I would like to first conduct a walk through of the basic cockpit to pilot interfaces--the controls, external visibility, the seats, and some of the things that differentiate helicopter control from airplane control.

Seat Assignment

When a pilot gets into most helicopters (there is always an exception) he flies from the right side. This is true even though there is really no rational reason for such a choice. In fact, when you consider the need to work with airplanes in left-hand traffic patterns, it makes little sense at all. For when the helicopter is in a left bank, the pilot in the right seat generally can't see where he is going during the turn. The pilot's line of sight is blocked by the overhead of the cockpit cabin which normally supports circuit breakers, switches, and engine controls.

The real reason helicopter pilot's are in the right seat has nothing to do with any great engineering logic. It just happened to come out that way. Mr. Sikorsky meant for the pilot to be in the left seat, but because of early vehicle training problems, the first operational pilots learned to fly in the right seat. The point here is that there is nothing sacred about the pilot being in the right seat. But is there any reason to consider changes? There may be.

Approaching a hover spot the pilot must flare to stop. When he flares the view over the nose is often inadequate. When it is, or when there is an obstruction in the over-run, the pilot will often approach with a crab angle. A sideward flare will be used, or the helicopter will be stopped short and air-taxied so that the pilot can see the spot out the right side. When this type of approach is flown in U.S. helicopters, left pedal is required to sideslip to the right. More left pedal means that more tail rotor power is required. If the pilot were to sit on the left side he would hold right pedal and less power would be required to maintain hover altitude. Seems like the U.S. helicopter pilot is on the wrong side or the U.S. main rotor is turning the wrong way.

Collective

The importance of the collective and its control characteristics are substantially underappreciated by the helicopter community. This device should be recognized as a direct lift control, that permits precise and quick control of the vertical degree of freedom. The stored angular momentum permits small inputs to be accomplished without the need to trade airspeed for altitude and without concern for the engine(s') ability to accelerate or decelerate. Figure 1 further illustrates how the collective can be used to climb even while the nose is pushed over to accelerate and allow the pilot to keep the trees in visual contact.

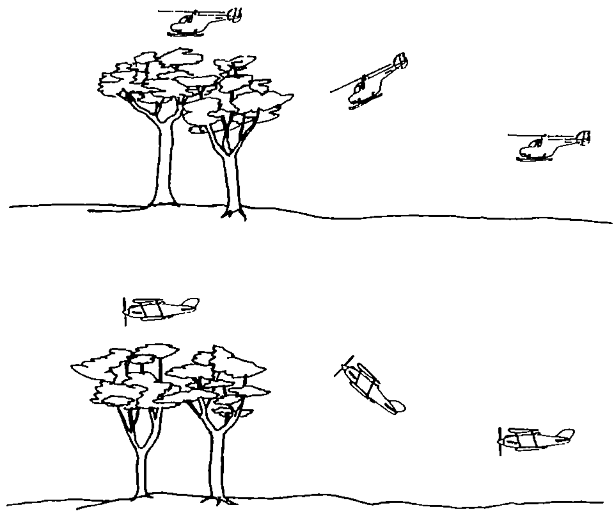

Figure 1. Comparison of Airplane and Helicopter Pitch Attitude Characteristics During Climb Over Obstruction.

When compared to the airplane task, the collective simplifies height control; but it makes horizontal speed control comparatively more difficult. For example, when an airplane pilot climbs back to glideslope, power is added and the nose is raised to increase angle-of-attack. In contrast, the helicopter pilot simply increases collective to climb. To change speed at constant altitude, the airplane pilot simply reduces thrust and the aircraft decelerates. Altitude is maintained via the elevator. The helicopter pilot pitches nose up and commands deceleration with attitude while maintaining height via the collective. This last technique requires more control coordination.

Some analysts tend to believe that airplanes and helicopters are controlled in the same basic way. Engineers with this viewpoint will read the two sets of descriptions above, and conclude that the airplane techniques and the helicopter techniques in forward flight are essentially the same. And this is where many of the helicopter pilot's problems begin.

On a more positive note, there has been one noteworthy innovation in physical design of the collective control. This new design was first installed on the Bell-222 and later on the Bell 214ST. The collective grip tends to move aft and upward as collective pitch is increased. I had no problem with this motion. The hand grip and arm motion were very comfortable. But more important, this design permits the installation of two engine controls on the collective. The left side of the split grip is for the No. 1 engine and the right side is for No. 2. With this design, one can readily advance or retard an engine in an emergency without releasing the collective. An admirable solution to a difficult problem (see Figure 2).

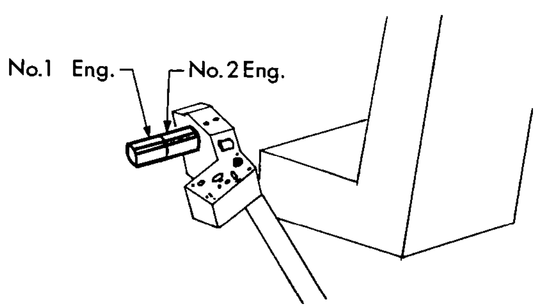

Figure 2. Characterization of the Collective Control Incorporated in the Bell-222 and Bell-214ST Helicopters.

Linear Force Cues

To further understand helicopter control techniques and the need for enhanced visual cues, it can be useful to consider the nature of the linear accelerations which are felt by the pilot (airplane vs helicopter) during a level deceleration. Consider the case where the throttle of an airplane is rapidly retarded. The linear force along the X axis causes the pilot to move forward, and is restrained by a seat belt and shoulder harness. In contrast, the pilot of a helicopter decelerates by lowering the collective as he pulls the nose up. If the pilot doesn't lean forward (so as to see out or keep his vertical orientation), the result can be no forces or an increase in the forces on the pilot's back as gravity pulls him against the seat.

Seats-Controls

Engineers underestimate the need for adjustable seats and pedals. The pilot must be able to comfortably locate himself around the controls. This includes the pedals which need to be adjustable as well. A pilot who is uncomfortable or must sit on an angle, is probably more susceptible to spatial disorientation.

Looking a little deeper, we find many pilots fly with their right forearm resting on their right leg, manipulating the cyclic control with their fingers. This is a method which is particularly appropriate for IMC flight. I fly this way and often feel like I have to adjust the seat too high relative to the pedals, just to obtain a satisfactory grip on the cyclic. I don't really see anything which one might do to improve pedal positioning but a cyclic which could be adjusted in height an inch or two might enhance many pilots' abilities to fit into their machine. Again it's important to be comfortable to avoid disorientation during high stress or high workload situations.

Force Trim Systems

There should be a cyclic force trim system in all IMC capable helicopters. This system should always incorporate an instantaneous Force Trim Release (FTR) switch, even if the system uses a Four Way Trim Switch (FWTS Coolie Hat) to trim fore and aft, and laterally (see Figure 3).

A simple force trim system is required to hold the cyclic control where the pilot puts it. And when such a spring system is added, the designer should not become confused as to its purpose. In a helicopter the Force Trim system holds the control at some pre-selected point. That is, the longitudinal and lateral-directional

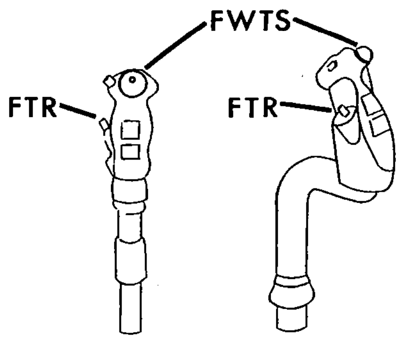

Figure 3. Typical Cyclic Control.

static stability of a helicopter are generally so weak that the force characteristics which can be developed (via a simple force feel system) do not substantially enhance helicopter handling qualities. But when augmentation is incorporated, it does become very important for the control to stay precisely where the pilot puts it.

In contrast, putting a force feel spring in the yaw control is totally counterproductive. Friction is more than adequate to hold the controls in place. And if you put a spring in yaw, the pilot is forever pushing the FTR switch so that the pedals can be repositioned. If the FTR releases cyclic trim at the same time the yaw control is released, you have defeated the reason for the cyclic force gradient. The best design, from a pilot's point of view, incorporates friction to hold the pedals in place, with the possible addition of a hysteresis damper that provides an opposing force, proportional to the rate of application. For VMC type maneuvers, the pedal rate damper is even more appropriate. That is, the pilot obtains the best feel for the maneuver he is conducting if he feels a control force which is proportional to the rate a given control is deflected.

This type of control rate damper can also be incorporated in the cyclic control with advantage. This is true because many pilots depress the FTR to release the stick centering forces during rapid maneuvering. If the rate feedback forces remain, even when the FTR is depressed, the pilot's reaction is very positive.

Visibility

There is a great deal of variation between designs when it comes to cockpit visibility. The importance of external visibility is hard to overstate. Yet, it is an aspect of design which seems to receive insufficient weight when cockpits are configured (see Figure 4).

For example, the need to see down through the feet seems to be one of the least appreciated needs for visibility. Yet the pilot receives much visual data through peripheral vision when he can see the ground down through or near the feet. In slow speed flight or hover, horizontal motion is best controlled via this cue source. It is even possible to receive a beneficial cue of pitch rate through this window when in a hover or even at altitude when operating without a horizon.

Some helicopters have little or no downward visibility, and experience has shown that they are clearly more difficult to land with equal precision. And flares from steep approaches are much more readily accomplished when the downward visual path is available. When forward visibility is poor, as it is during heavy haze, and at the bottom of an IMC approach, the pilot may actually acquire initial visual contact through the lower panel. This can happen even when he is heads up looking for the landing area. And when you depart vertically out of a confined area, there is no substitute for this downward visibility.

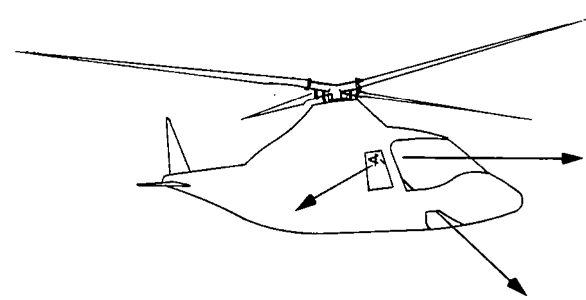

Figure 4. Typical Sources of Pilots Primary Visual Cues.

Another problem occurs during attempts to conduct steep approaches. This is illustrated in Figure 5. Here the pilot visually acquires the landing pad with his eye on a 20 degree approach angle. This is his limit of downward vision over the nose so that when he pitches up to decelerate, he loses visual contact with the pad. So he doesn't pitch up first. First he lowers the collective and flies down. As he descends he becomes able to pitch up for the deceleration while still keeping the target in sight. This may explain how tail rotors get involved in trees and fences on final approaches to confined areas.

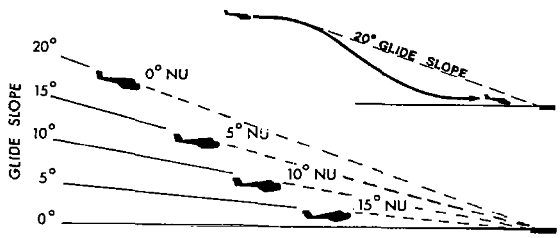

Figure 5. Flight Path Flown when Pilot Attempts to Keep Landing Site in View After Having Started a Steep Approach.

Horizon Reference

When the sun goes down, and the horizon reference weakens, the pilot trades the outside visual cues for the information available from the cockpit displays, aircraft sounds, cockpit control positions (and forces) and the force cues (vertical accelerations, etc.) impressed upon his person. In many cases there is a period of transition where the pilot is flying via primary reference to his instruments even through some of the outside cues are still there. During such periods the pilot can experience an unexplained uneasiness, and for some reason there is a problem keeping the ball centered on the inclinometer.

I believe this situation also develops during transitions from IMC to VMC on final approach and during certain other slow-speed hover tasks. This uneasiness is also related to the aircraft where a pilot has a much different feel when flying from right seat as compared to the left. A probable explanation is illustrated in Figure 6.

When the glass shield is curved, or it is sloped down to the outside, the pilot is presented a very strong erroneous attitude reference. And under certain circumstances, I believe there is an unconscious tendency to match the horizon and the glare shield line. This causes the ball to be out to the left when the pilot flies and out to the right when the co-pilot flies. This glare shield line needs to be truly level. When the aircraft visual reference is level, a weak horizon line, can be a powerful positive cue even when no conscious reference is made to it.

During night hover operation in the SH-3, it was not uncommon to work with no horizon. (Even if there is a horizon you still fly the machine on instruments). But there would be nights when just a faint hint of a horizon line was available. One never looks at it, but somehow you

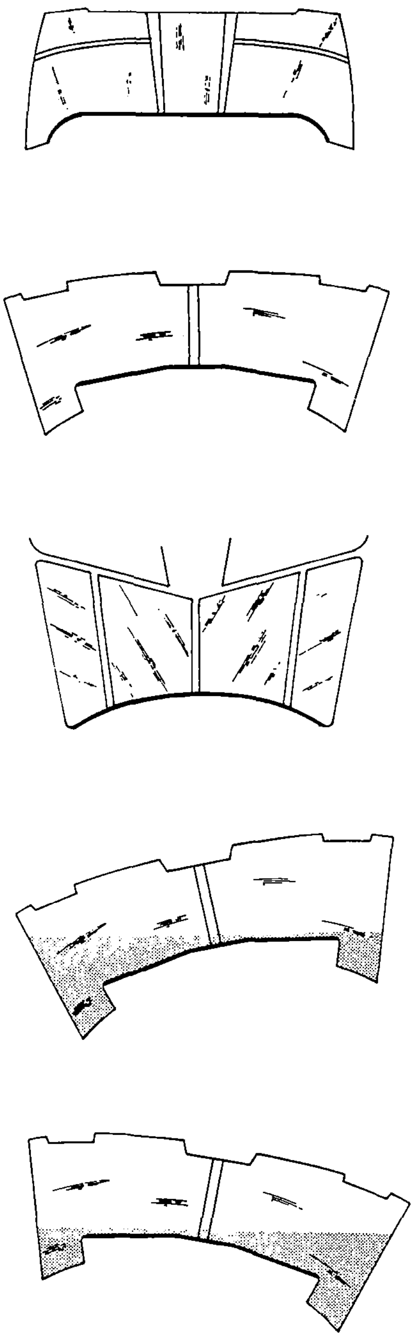

Figure 6. Impact of Glare Shield Design on Crew Visualization of the Wings Level Attitude.

would know it was there. But the running lights (navigation lights) would backscatter light into the cockpit from the mist over the ocean and this would often mask the faintest of horizons. When I was tired and I was uncomfortable, I would turn the running lights out (leaving the tail light on) while I hovered. I could then faintly make out the horizon reference and it made all the difference.

The IMC Problem

In a historical sense, the design of today's conventional IMC cockpit, was derived from a marriage of airplane instrumentation to the cockpits of helicopters which were originally designed for visual flight only. And when helicopter pilots were unable to accomplish an IMC hover, or an approach to hover on instruments, vehicle stability took a large share of the blame. Automatic Flight Control Systems (AFCS) were subsequently incorporated to solve the problem. The result was a dramatic improvement in man-machine performance, but the man had a new role. The pilot was now a manager, no longer in the direct control of the helicopter. The pilot became a safety pilot. He was able to fine tune the AFCS while it operated normally, while also being there to recognize failures so as to extract the aircraft from an approach or hover task if safe limits were exceeded.

Next came the Flight Director Indicator (FDI) which in many cases could double as an Auto Pilot Computer (APC). The FDI brought the pilot back into the direct control of the aircraft, but this time he was a servo. The pilot was instructed to follow commands on an ADI, matching pointers to their respective indices. Keeping all the pointers in their proper place would keep the aircraft on glide slope or in a hover. The two big advantages of this display format were that the pilot didn't have to think much, and all commands were centrally located on a single display. I might add that the basic flying qualities of the helicopter were improved so that Auto Pilots could control the outer loop. When this happened, it became possible for the pilot to fly almost as well with an FDI. But even when pilots are allowed to fly with reference to an FDI, they are typically required to operate above say 60 knots, unless features like heading hold are incorporated.

Collective to Yaw Couple

This last point is very important. The heading hold feature is required to accomplish an approach to hover (IMC) because the collective to yaw couple of the single rotor helicopter is so powerful and interactive that it dramatically increases pilot workload when it goes unchecked. Heading hold is not required to compensate for poor static directional stability; nor is control quality or control power of the directional control system at fault. The problem clearly stems from the fact that it is difficult to find the new directional control trim point when an input is required to compensate for the collective-to-yaw couple.

The desired yaw control position, which the pilot cannot easily locate, is the position which will yield a zero yaw rate. He does fine when visual cues are available, but during IMC he has trouble because the yaw rate cues available in the cockpit are totally inadequate. To understand why, lets review the fundamentals and actual experience.

When the collective of a U.S. helicopter is increased during hovering flight, the pilot must move the left pedal forward to compensate for an increase in main rotor torque. Right pedal is required under similar circumstances in a French helicopter where the main rotor turns in a direction which is opposite to that of the U.S. machine. One might expect a pilot to have trouble switching from the U.S. to the European convention. But generally there are no problems at all when the yaw rate cues are sufficiently strong. But some piloting errors do occur when the strength of the heading-rate cue decreases.

In reviewing my own experience, I can report that I have had no problem associated with takeoff or hovering flight; but at high altitude or while operating in heavy haze, I have found my left foot moving forward with up collective. That is, when the visual cues were powerful, I had no problem. But when the cues were weak, my learned response (which was nurtured for 22 years in U.S. helicopters) took over, even in the European machine.

This experience illustrates the importance of yaw rate cues. Although I had no problem adding right pedal with up collective during my first takeoff, I experienced confusion at altitude where the yaw rate cues were not lost, but distant and subdued. I didn't even have to enter IMC to start having trouble with directional control coordination.

Obviously static directional stability was not at fault. This parameter is obviously of greater aid during forward flight than in the hover where I had no problem at all. One can now conclude that the static directional stability and the yaw control system are adequate all the way to a hover. So what is missing?

For the answer, compare the function of the display which is provided for pitch and roll, to the function of the display(s) provided for yaw control (or heading). The ADI is a fine analog of the real world. A nominal one-for-one match. But look what has been provided for yaw. The most obvious instrument is the RMI (or HSI). The cue is a dial that rotates in an indicator which is mounted below the ADI. You would have to look down through a hole in the floor of the helicopter to see real world motion which would relate to this display. The RMI and HSI are navigation and heading management indicators, not yaw rate displays.

Then there is the vertical needle of the turn-and-bank indicator. Today this indicator is so small and underdamped that it is virtually useless during IMC hover or approach flight.

Electronic HSI's generally provide an enhanced heading cue, but again, the cue is displaced from the primary cues of pitch and roll found on the ADI.

In the most modern military helicopters, we find the Electronic Vertical Situation Display (EVSD). A heading reference strip is normally presented across the top of the display. This is a step in the right direction, but it is clearly not conventional equipment. In any event, it is not currently offered for civil machines and generally beyond the scope of this paper.

Now revisit the piloting task for a moment. During hover and approach to hover, speed changes require collective adjustments. The collective couples to yaw, yaw produces a sideslip, and the helicopter subsequently rolls and pitches as a result. So in a conventional cockpit, when the pilot makes an adjustment to the collective to stay on glide slope, he excites a chain reaction, a chain of couples that impact the equilibrium of the aircrft as though they were gust upsets. So an unattended collective-to-yaw couple upsets yaw, roll and pitch, with an attendant deviation from the desired flight path.

Consider a helicopter in an ILS approach, on speed but below glide slope. If the pilot tries to control glide slope with collective (as we teach him to do) he exacerbates the pitch and roll attitude control task. And pitch attitude is the primary means of airspeed control. Years of observation leave no doubt that as the attitude control task becomes more difficult, the pilot becomes highly stressed. And when the pilot operates under a sufficiently high level of stress, the feet stop working.

The feet are relatively dumb control elements. They work well when the cues are strong, but when the workload goes up, and the visual cues are poor, this is the first control path which fails the pilot. Under the stress of maintaining altitude (or glideslope) and pitch attitude, the pilot's scan breaks down and the displays which are not directly in his compressed scan are ineffective.

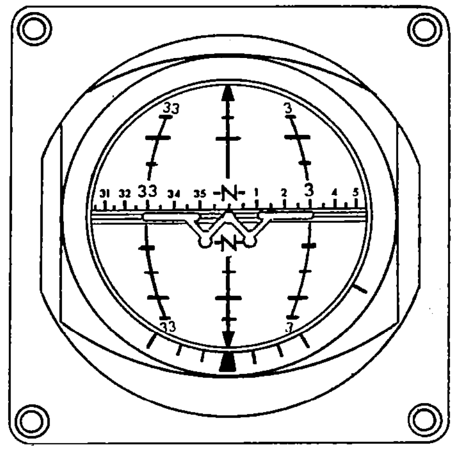

Figure 7. Pitch Roll Yaw Attitude Indicator (Characterized from ADI-811).

The yaw rate needle of the turn and bank indicator may still be in this compressed scan, but this indicator does not readily transfer the message. It does not exhibit any characteristics analogous to yaw rate and therefore it must be interpreted. Experience would suggest that control logic in the mind gives priority to control of the most life threatening parameter(s) and shuts down data inputs which either relate to low priority control or need interpretative processing. The turn needle fits both of these criteria for deferred priority. But if the cue is so strong that it works through peripheral viewing, the mind accepts and acts on the data. The explanation may not be entirely correct, but the observations of pilot response are absolutely accurate.

This brings us to consider one possible solution. Why not present heading on the attitude indicator? Rotate the attitude ball of the ADI when the aircraft turns. The cue will be so strong that it can be treated peripherally; as it is during VMC operations. The transfer is more real world. When you turn left the face of the indicator moves from left to right. This is not a new idea, it has been incorporated for years in combat aircraft (see Figure 7).

Height Control

Another problem control task in slow speed flight involves altitude control and maintenance of glide slope during IMC operation. As in the case of yaw control we find a quick, precise and powerful control in the collective. It is a direct lift device which has no lags to confuse its application. During VMC hover operations, one can hold hover height within inches of the desired value, even during turns and speed changes. But when the visual cues are gone, so is precision performance.

The pilot does feel vertical acceleration in the cockpit when a collective input is initiated. But during IMC maneuvers these forces are quite small and they often get masked by vibrations. Sometimes the vertical forces which are produced via (pitch) angular accelerations similarly mask collective inputs. So, as in the case of the yaw control, there are really no reliable natural cues which remain, once the external visuals are gone.

And as in the case of yaw control, we have another classic control trim problem. The pilot has a difficult time finding the control position for zero vertical rate. There are several reasons for this problem.

First, the trim point moves around anytime the horizontal speed changes. For example, starting from a stabilized constant altitude situation near hover, a small increase or decrease in horizontal airspeed will cause a change in the power required to maintain level flight. The aircraft then starts to climb or descend, requiring a collective adjustment to cancel this unwanted rate.

Reviewing the power required characteristic we find that the power for level flight decreases as speed decreases below V_{NE} in much the same way as it does for the airplane. It bottoms out in a typical bucket, then increases again to peak at zero airspeed. When speed is increased to the right, left, or rearward from zero, the power required by the rotor decreases in a way similar to forward flight (see Figure 8).

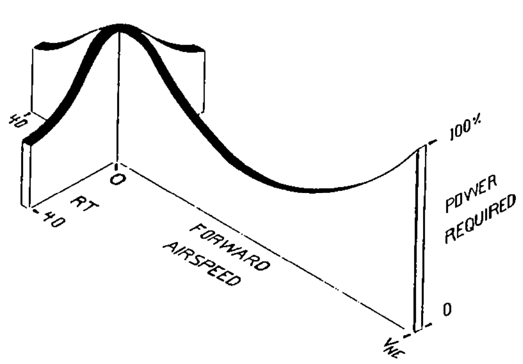

Figure 8. Helicopter Power Required for Level Flight.

The power curve is essentially flat or neutral in the bucket, stable on the front side and unstable on the back side. Finally, the gradient is typically much steeper in the slow speed regime than in high speed forward flight. The stability of the curve and the magnitude of the gradient all influence the pilot's ability to cope with the vertical degree of freedom. That is, all of these characteristics contribute to define the task. In summary, the task is least difficult on the front side and most difficult on the back side of the power curve. And it is easier to control the vertical degree of freedom with the collective when airspeed is held constant vs. control in conjunction with horizontal speed changes.

This doesn't mean to infer that the task is ever easy under IMC, slow-speed operations. Because the pilot must still observe the error and know how to precisely respond with the collective.

Take the easy case first. Flying an ILS approach, the glide slope signal is conventionally presented quite adequately. So visualizing "above" or "below" glide slope is not a problem. And in the real world we find pilots tend to lock down the collective with friction and use the cyclic control to fly up or down to achieve glide slope. This works during operation on the front side of the power curve which is where all civil IMC is flown.

Pilots probably use this technique for two reasons. They know they have trouble making accurate adjustments to the collective setting and that several adjustments will be required before they get it right. They also know that any collective change will require a directional control "pedal" input. We've already covered the last problem under the discussion of collective-to-yaw coupling. So why are there problems setting power (Collective)?

The pilot has no precise cue of collective position. When the pilot adjusts the collective he observes the results via a cockpit display of engine torque. But this indicated value of torque is subject to all sorts of masking. Changes in tail rotor thrust (pedal position), a nose up control input, a roll control input, a vertical gust, and a commanded change in rotor RPM will all cause the indicated torque to change more than the amount that the pilot typically needs to input to accomplish for a climb back to glide slope. So these miscellaneous inputs mask the pilot's collective input.

Another problem involves display location. Typically the torque indicator is displaced too far from the primary viewing area to be included in a high gain scan. This seems to be a very serious problem in the civil commmunity. In this

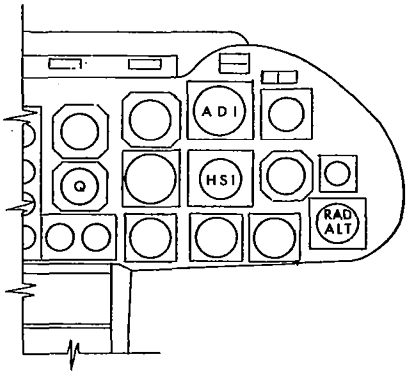

Figure 9. Typical Location of Radar Altitude Indicator and Engine Torque Meter (Q) Shown Relative to the Primary Attitude and Heading References.

group more priority is given to adding an additional attitude display than properly locating the torque indicator. (See "Q" in Figure 9).

Finally most torque indicators appear to be underdamped. I'm not sure why they are underdamped, but I believe this damping characteristic contributes to the problem of selecting the desired power setting. For in one case, a properly damped indication of main rotor torque (Bell-222) provided excellent results (as illustrated in Figure 10). Yet would anyone seriously consider asking an Auto Pilot to close the vertical control loop on torque information?

Designers of FDI's for helicopters were faced by the same problem, a problem which they solved by including a small edge mounted pointer to indicate collective control inputs. It is not the ultimate device but its presence lends credibility to the need. From personal experience I can say that a clear indication of collective position allows pilots to find trim very quickly with an absolute minimum of effort. So the solution is a full range collective position indicator.

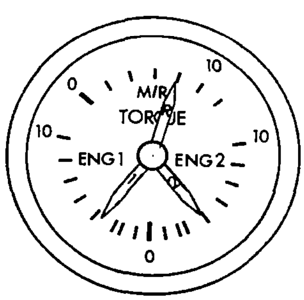

Figure 10. Characterization of Torque Meter Used in the Bell-222 Model Helicopter.

Radar Altitude

When we complete an IMC approach to a hover, and hold an IMC hover, another cue deficiency becomes evident. Arriving at the Decision Height (DH) altitude the pilot becomes more aware of his absolute altitude above the ground. And another instrument becomes important, the radar altimeter. And where is it located? In civil helicopters it is typically found in the lower right hand corner (see Figure 9).

This is a totally unsatisfactory location for such important data. The standard pressure altimeter is simply not adequate during transitions to, and operations in, the low-speed regime. Both altitude and altitude rate are unreliable to the degree generally required for controlling height during an IMC hover. Since radar altitude and visually derived "radar altitude rate" are the best cues available in the cockpit, these data need to be presented with higher priority in the cockpit. The display should be given higher priority, but I have another solution which seems to work very well. This solution is illustrated in Figure 11. Here the Decision Height (DH) and Radar Altitude are presented digitally on the lower edge of the ADI. This is an excellent format for the final phase of the ILS approach. The display I evaluated is by Sperry. It has an update rate which appears to be well suited to the task of interpreting radar altitude rate as well. If this is an accurate assessment, such a display clearly would enhance a pilot's ability to hover and maneuver in the slow speed regime. The Sperry ADI evaluated also has a rising runway indicator to display absolute height. I agree that this is a proper approach but not the total answer.

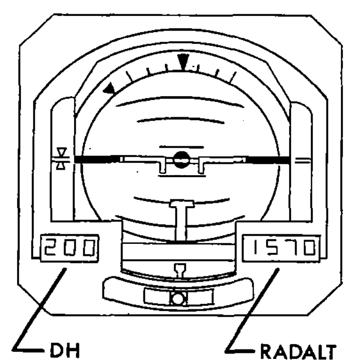

Figure 11. ADI Including Digital Presentation of Decision Height and Radar Altitude.

Back-Side Speed Control

Then there is the problem of speed control on the back side of the power curve. The power required curve typically has a steep gradient on the back side of the curve. And the slope represents an unstable situation when considered in the context of man-machine control. That is, if the aircraft slows down it will descend. This means that to climb back on glide slope the pilot cannot simply pull up (flare) and trade airspeed to regain the glide slope. Such an act causes the aircraft to lose speed, with a momentary positive response but then the aircraft settles further below glide slope.

So during a slow speed aproach, the collective is clearly the control which the pilot must use to modulate descent rate or angle. And to simplify the control activity, it is necessary to hold airspeed constant. But again there is a problem with the data available to the pilot.

Airspeed Display

When power is added, most pitot-static airspeed systems reflect an apparent change in airspeed. A change in slideslip angle or angle-of-attack will have a similar result. So even at airspeeds where the pitot-static airspeed system is still supposed to function (above 40 knots) the pilot can find himself chasing changes in "position error". Thus, he actually causes speed changes to occur in a needless attempt to hold speed constant. The real speed changes are therefore confused with the changes produced by changing values of position error, and the precision of the entire approach task deteriorates.

To avoid reliance on pitot-static airspeed, pilots are told to maintain a constant pitch attitude to hold airspeed. They are also told that more and more nose down trim attitude will produce a faster and faster trim airspeed, and vice a versa. The first concept is true only if the second is true. That is, the variation of pitch attitude must be stable or at least neutral before one can use pitch attitude to reliably attain and hold airspeed. In most cases the stable attitude characteristic required and desired does not exist.

Since pitot-static airspeed indicators become totally inoperative below about 40 knots anyway (depending on the aircraft and the flight profile), some sort of reliable speed cue is required so that a pilot can separate the speed control task from the vertical control task. Ground speed can be derived from many current equipments, so that is one possibility. But the aircraft is actually responding to the airmass, not ground speed. So it seems obvious that an airspeed system which operates down to zero airspeed is clearly required.

Again we are faced with a question of where to locate this additional data display. Collins in cooperation with PACER Systems, Inc. is developing such a display for the U.S. Navy (see Figure 12). This display is multi-mode, allowing both pitot-static and omnidirectional low range airspeed to be presented on a single indicator. Thus it can one-for-one replace the current airspeed indicator.

Experience has shown that this type of airspeed data is not subject to the problems that plague the pitot-static system. Now the pilot can use the longitudinal control to directly regulate airspeed. He no longer must try to hold a constant attitude to determine, after some several seconds, what might happen to airspeed. Thus, we have decreased the amount of time that the pilot must allocate to the ADI to accomplish the airspeed control task. This reduction in workload further releases the pilot's control logic to handle the heading and attitude control tasks discussed earlier.

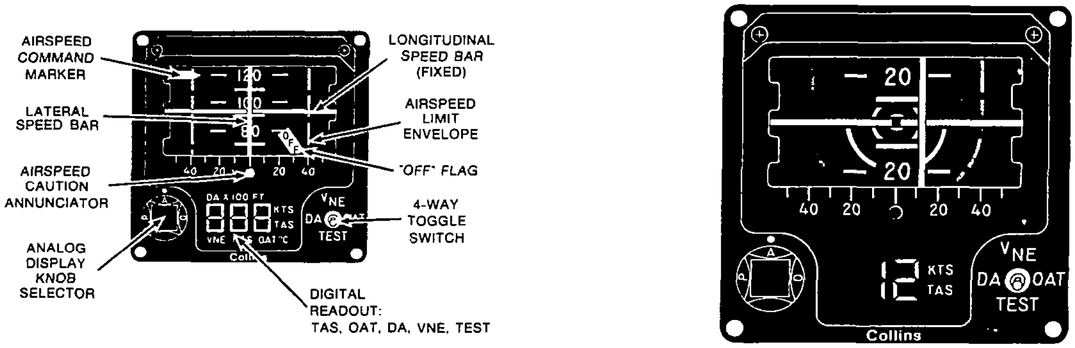

Figure 12. Collins ASI-800, Omnidirectional Airspeed Indicator (OAI).

Now the pilot is in a position to use airspeed and all the other new cues to get ahead of the aircraft. He no longer must put in control inputs and wait to see a response. In actual practice, the pilot can learn to anticipate the amount of collective change which is required to maintain level flight (or glide slope) as speed is gradually changed.

Since the Omnidirectional Airspeed Indicator (OAI) of Figure 12 is able to present airspeed for flight in all directions from zero, it is also now possible for pilots to observe the cross wind component as just that, a component of airspeed. They can learn what 5, 10, and 20 knot components will mean as he decelerates and achieves a hover. And when the component is too high for safe operations, the pilot will be able to anticipate the situation before an unmanageable hover is attempted near obstructions, etc.

The Landing

To land under IMC conditions, I would expect that for some long number of years into the future, pilots will be required to have visual contact with the ground. I really see no reason why there should ever be any reason for a CAT III type flight control system in a helicopter. What the industry needs is a system which the pilot can use to get into close proximity to the landing surface. I have hovered in some really dense fogs, but I can never remember a case where I couldn't see the ground at 20 feet. Here is where downward visibility re-enters the picture. Nothing is as accurate and reliable as the pilot when it comes to accomplishing a vertical landing. So mostly the problem is stopping the helicopter over the landing pad, at an altitude of 50 feet or less. With excellent downward visibility the pilot continues to fly the aircraft down to a touchdown.

Conclusions

In conclusion, let's review the highlights. Reducing the workload associated with horizontal speed control reduces the pilot's workload so that he is better able to use the other display-control enhancements such as:

- Pitch-Roll-Yaw Attitude Indicator
- Collective Position Indicator
- Radar Altitude Indicator
- Excellent downward visability

The net result is to bring the pilot's control task in line with what a human could be expected to achieve. The more the pilot can achieve with the basic helicopter the more viable the helicopter will become in civil and military applications.