Evaluation of ADS-33E Cargo Helicopter Requirements Using a CH-53G

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Flight tests with a Sikorsky CH-53G of the German Federal Armed Forces were conducted in Germany under the U.S./German Memorandum of Understanding (MoU) for Cooperative Research in Helicopter Aeromechanics to evaluate the cargo helicopter requirements of the U.S. Army Aeronautical Design Standard-33 (ADS-33E-PRF). The tests were carried out by the Wehrtechnische Dienststelle 61 (WTD 61, the German Armed Forces Technical and Airworthiness Center for Aircraft and Aeronautical Equipment), the German Aerospace Center (DLR), and the U.S. Army Aeroflighdynamics Directorate (AFDD). Quantitative data for hover and 100 knot forward flight were gathered. Five test pilots flew the Mission Task Elements in good visual environment and gave handling qualities ratings for thirteen Mission Task Elements as listed in ADS-33E-PRF, including the evaluation of handling qualities with an external slung load. The objective of this test was to evaluate the applicability of the ADS-33E-PRF cargo helicopter requirements using a helicopter with conventional main and tail-rotor configuration. Assessing the related handling qualities of the CH-53G is the means to do so, not the objective. This paper describes the test set-up, the main pilot comments and handling qualities ratings, and the initial results and lessons learned with respect to ADS-33E-PRF.

INTRODUCTION

In the early 1980´s, the development of a new military helicopter handling qualities specification superseding MIL-H-8501 started in the United States at the AFDD. The result was the Aeronautical Design Standard (ADS)-33. It includes definitions of aircraft response characteristics dependant on the visible cues, quantitative criteria in the frequency and time domain as well as qualitative criteria that are based on pilot ratings (Ref. 1). Several organizations supported the requirement development process with piloted simulations and flight tests (see e.g. Ref. 2-12). AFDD and DLR collaborated on pitch-roll coupling research, the results of which now form the coupling requirements in ADS-33 for target acquisition and track. The latest version, ADS-33E-PRF (Ref. 13), was released in March 2000, and is accepted internationally as a valuable contribution to the definition of requirements for military helicopter handling qualities (see e.g. Ref. 14, 15, 16).

Since the main focus of the work that contributed to the first version of ADS-33 was on scout and attack rotorcraft, cargo mission requirements including operations with external loads were not addressed. The U.S. Army Airworthiness Qualification Test Directorate (AQTD) was tasked by the Aviation and Troop Command to conduct flight tests with a Boeing CH-47D, a tandem-rotor cargo helicopter, from 1993 to 1995 to develop handling qualities requirements for cargo transport missions to be included in ADS-33 (Ref. 17, 18). The helicopter was tested up to 46,800 lb (94 % maximum gross weight) with an internal load and 48,000 lb (96 % maximum gross weight) with an external load. The results were incorporated in the E-version of ADS-33. In addition it was explicitly proposed to undertake a comparable evaluation with a single rotor production cargo helicopter to corroborate the findings of the CH-47D tests and identify any fundamental differences or tandem rotor biases (Ref. 18). To do so and to extend the ADS-33 database for cargo helicopters with a conventional main and tail

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rotor configuration, in 2004/5 flight tests were conducted with a Sikorsky CH-53G of the German Federal Armed Forces. Test preparation began mid 2004, with the general set-up of the test aircraft and the data gathering systems. By the end of 2004, the first phase of flight tests related to choosing and defining the Mission Task Elements (MTEs) to be flown, the set-up of the ground courses, pilot training, and finalizing of the MTEs, including first pilot feedback, was completed. During a second phase (May-April 2005), quantitative data were collected. The pilot handling qualities ratings (HQRs) were gathered in a third phase in July and August 2005. Five test pilots flew the MTEs and provided ratings. A total of 27 flights for 40.5 flight-hours were flown from November 2004 to mid August 2005.

This paper describes the test aircraft, the data gathering systems and process, the test site and test matrix, the MTEs evaluated as well as the conduct of the test, and presents the Cooper-Harper Handling Qualities Ratings (HQR) including detailed analysis of scatter. Lessons learned regarding the MTE layout and proposals for modifications to ADS-33E-PRF will also be given.

TEST AIRCRAFT

From 1972 to 1975, 110 Sikorsky CH-53G aircraft were built in Germany under license for the German Armed Forces. VFW Fokker had the program lead and MTU, Dornier, and MBB were involved in the manufacturing process. Data on the CH-53G is given in Table 1.

Conventional mechanical helicopter controls are provided for both pilot and copilot. The controls are augmented by two parallel and independent hydraulic servo systems. Collective control is cross fed to both the lateral cyclic and tail rotor controls to offset roll and yaw moments produced by collective pitch changes. An electronic automatic flight control system (AFCS) is implemented, which includes command augmentation of longitudinal cyclic control, rate damping about all axes, attitude and heading stabilization, and turn coordination at indicated airspeeds above 60 knots. The aircraft employs automatic control force trim functions for the lateral cyclic stick and for the rudder pedals. The landing gear, front and main, is retractable and the main landing gear has parking brakes. Two CH-53G aircraft were used for the ADS-33E-PRF evaluation. The aircraft used for the final evaluation and data gathering, call sign 84+02, is equipped with a data gathering system including a nose boom with air data sensors and is shown in Figure 1. Another aircraft, not equipped with a data gathering system, was used for the first phase and for pilot training.

Figure 1. WTD 61 Sikorsky CH-53G testbed.

Table 1: Sikorsky CH-53G data.

MANUFACTURER	Sikorsky Aircraft Co. (United Technologies), Stratford, CT, USA		
LICENCER	VFW Fokker (co-operating with MTU, MBB, Dornier)		
ENGINES		**MAIN ROTOR**	
Manufacturer	General Electric	Type	articulated
Type	2 x T-64-GE-7	Number of blades	6
Max. power (< 10 min.)	2 x 2,927 kW	Diameter	72 ft (22.02 m)
Mil. power (< 30 min.)	2 x 2,755 kW	Normal rpm	185 rpm (19.4 rad/s)
Cont. power	2 x 2,409 kW	Shaft tilt	5 deg forward
WEIGHTS		**TAIL ROTOR**	
Max. take-off weight	42,000 lb (19,050 kg)	Number of blades	4
Min. take-off weight	30,000 lb (13,608 kg)	Diameter	16 ft (4.88 m)
Empty weight	23,589 lb (10,700 kg)	Normal rpm	788 rpm (82.8 rad/s)
Max. external load	15,983 lb (7,250 kg)	Blade chord	1.28 ft (0.39 m)
Max. load (full fuel tanks)	12,125 lb (5,500 kg)		
		PERFORMANCE	
DIMENSIONS		Max. speed @ SL	170 kt (315 km/h)
Fuselage length	67.3 ft (20.5 m)	Cruise speed @ SL	150 kt (278 km/h)
Fuselage width	8.8 ft (2.69 m)	Max. sideward speed	35 kt (65 km/h)
Overall length	88.3 ft (26.9 m)	Max. backward speed	30 kt (56 km/h)
Overall width	15.5 ft (4.72 m)	Min. / Max. load factor	-0.5 g / 2.38 g

DATA GATHERING

Onboard system
Flight dynamics data such as pilot stick position and aircraft attitudes and rates, etc. were recorded with an onboard data gathering system throughout all quantitative and MTE flights. The main part of this data gathering and recording system was installed in the left front of the aircraft cabin, including a monitor and seat for the Flight Test Engineer (FTE). Eighty parameters were recorded on tape at 120 Hz and simultaneously transmitted to a telemetry station for online monitoring. The data recorded included air data measured on a noseboom and by the basic aircraft sensors, the control positions (cyclic, pedal and collective) before and after the AFCS actuators, engine torque, and aircraft body attitudes, rates and translational accelerations. In addition two video cameras were installed, one in the cockpit viewing out the front window capturing roughly the pilot's front view, and one looking down the cargo hook to capture the load movement.

Track data
During the MTE flights the three dimensional aircraft track was measured with a Video-Kinetheodolite (VKth) system, an optical tracking instrument capable of tracking airborne targets. A definite point on the aircraft is focused on by two cameras located in a master and slave station at a distance approximately 1500 m from each other. The reference positions of the camera platforms are fixed and known and azimuth and elevation of both cameras are measured while tracking. The tracked point in space can be calculated from these data. With an MTE task reference coordinate system defined, the tracked point can automatically be transferred and delivered with respect to this reference system. The accuracy is about ±4 in (±10 cm). During most of the MTEs the front wheel was tracked, except for the Slope Landing and the Vertical Maneuver. For these two MTEs the alignment of the aircraft with respect to the tracking stations resulted in a limited visibility of the front wheel, therefore the main rotor head was tracked. The offset of pilot's eye position to front wheel or main rotor head was corrected for in post processing of the track data.

Pilots' questionnaires
After performing an MTE, each evaluation pilot filled out a questionnaire. This included rating the aggressiveness, the task performance, the system characteristics, the workload, and giving an HQR according to the Cooper-Harper rating scale. The reasons for each separate rating were included, as well as a rating of PIO tendency, if any. With five pilots flying 13 MTEs, this provides 65 questionnaires documenting the pilots' information.

TEST SITE

The flight tests were performed at the WTD 61 airfield near Manching, in the south of Germany. All of the MTE courses were set up on the cargo dropping area of the WTD 61, a plane area of about 2500 x 1000 m^2, covered mainly with grass. Several straight concrete roads with concrete circles at the intersections allow driving onto the area. These roads and circles provided very useful references for setting up the ground courses and were even used as visual cues for the MTEs. The VKth stations, located at the south of the area, are able to track a moving target everywhere on the area. An 8.9-degree slope (CH-53G slope limit: 10 degrees), was built on the north end of the dropping area and was used for the Slope Landing MTE (Figure 2). It has since been expanded and now dedicated slopes of 6, 8.9, and 12 degrees exist. The WTD 61 cargo dropping area provides an excellent means to have all relevant MTE courses available in parallel throughout the complete period of flight testing.

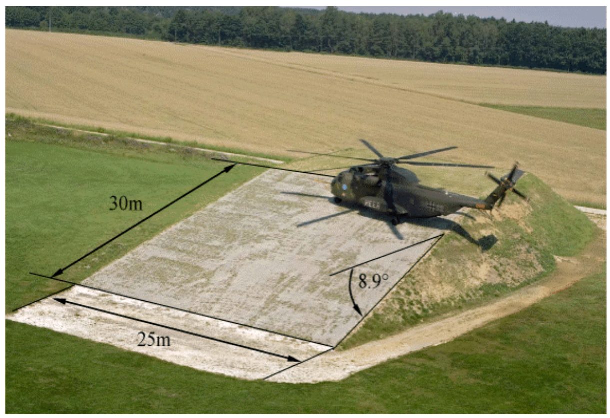


Figure 2. Slope on WTD 61 cargo dropping area.

TEST MATRIX

Quantitative data
Quantitative data were gathered in hover and 100 knots forward flight for all axes with 33,400 lb (80 % maximum gross weight) takeoff weight and mid c.g., see Table 2 and Table 3. Due to safety reasons, frequency sweeps were only flown in hover for pitch and roll axes. Pulses, steps and doublets of 10 to 20% control position excursions around trim were generated in every control axis in both flight conditions. Four flights resulting in a total of 5h 05 min flight time were needed to collect the data, including an additional flight that was made near the end of 2005 to collect missing data for attitude quickness analysis. This was necessary because the pitch AFCS function includes an attitude feedback resulting in an aircraft response in pitch which is not a rate response-type, see Figure 3. This made

Table 2: Hover tests performed.

Test Techniques	Axis	Requirement	ADS-33E-PRF paragraph
Trim	all	Equilibrium	3.3.1
Frequency Sweeps	Roll Pitch	Attitude bandwidth	3.3.2.1
Pulse inputs	Roll Pitch Yaw	Damping ratio	3.3.2.3 3.3.5.2
Step inputs	Roll Pitch Yaw Col.	Max. rate, Coupling, Response to coll. controller	3.3.4 3.3.8 3.3.9 3.3.10
Attitude capture	Pitch Roll Yaw	Attitude quickness	3.3.3 3.3.6

Table 3: Forward flight tests performed.

Test Techniques	Axis	Requirement	ADS-33E-PRF paragraph
Pulse inputs	Roll Pitch	Damping ratio	3.4.1.2
Step inputs	Roll Pitch Yaw Col.	Static stability, Coupling, Max. rate, Heading	3.4.4 3.4.5 3.4.6 3.4.8.2
Doublet inputs	Yaw	Lateral-direct. stability,	3.4.9
Steady Sideslip	Roll Yaw	Roll-sideslip coupling, Lateral-direct. characteristics	3.4.7 3.4.10
Attitude capture	Roll	Attitude quickness	3.4.6.2

different control inputs than pulses necessary to achieve a pitch angle change suitable for quickness analysis. Pitch attitude changes up to 20 degrees from trim, roll attitude changes up to 50 degrees, and heading changes from 10 up to 60 degrees in both directions were performed in hover. In 100 knots forward flight, roll attitude changes from 10 to 50 degrees were performed. Analysis of the quantitative data is ongoing and was not complete at the writing of this paper. These results and correlation with the flight test maneuver evaluations will be reported in a future publication.

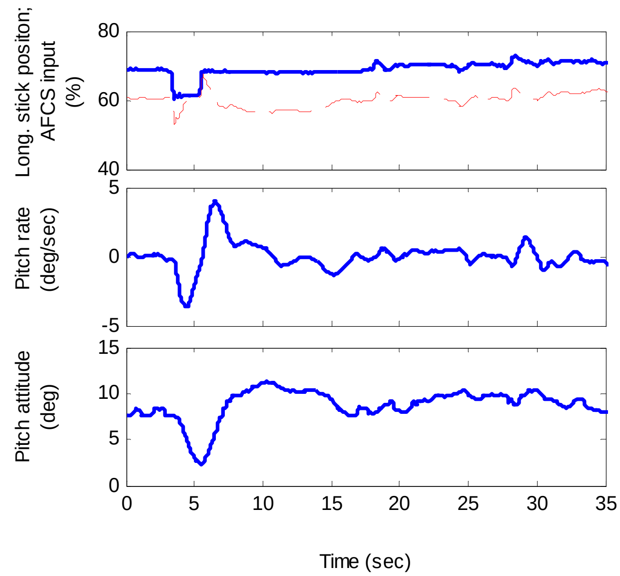


Figure 3: Longitudinal cyclic pulse input in hover (dashed: input after AFCS).

Mission Task Elements

The following MTEs were identified as primarily relevant for cargo mission and were therefore flight tested:

1. Hover
2. Hover Turn *(right and left)*
3. Lateral Reposition *(to right only)*
4. Depart / Abort
5. Vertical Maneuver
6. Slalom *(left turn first only)*
7. Pirouette *(right and left)*
8. Slope Landing *(right, left, and nose upslope)*
9. Landing
10. Hover with External Load
11. Lateral Reposition with External Load *(to right only)*
12. Depart / Abort with External Load
13. Vertical Maneuver with External Load

The MTEs were flown at a takeoff weight of 34,000 lb (81 % maximum gross weight) for the internal load configuration. The takeoff gross weight of the external load configuration was 38,800 lb (92 % maximum gross weight). The external load, an 8,818 lb (4000 kg) concrete block, was attached to the single cargo hook of the aircraft using an extension device with an additional hook, see Figure 4. To release the load, this second hook is opened. The performance standards were identical to ADS-33E-PRF. All evaluation flights were made with a mid c.g. in a good visual environment (GVE) only. Fifteen data gathering flights for 22.5 flight-hours were needed to get all the HQRs from all pilots, not counting various training and re-familiarization flights.

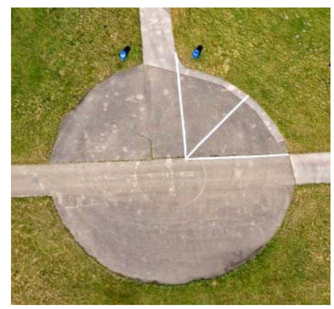
CONDUCT OF TEST

The CH-53G ADS-33E-PRF flight tests started mid 2004 with the preparation of the test aircraft, mainly for reconfiguration of the onboard data gathering system and removing of test equipment of an earlier test program. In parallel, the relevant MTEs were chosen, the design of the ground courses was discussed, and the set-up initiated. Designing and building the ground courses took roughly three months. Traffic cones, barrels, reference symbols and boards were used as position cues. Each cone was fixed to the grass covered ground of the cargo dropping area with four long nails while the barrels were filled with water or sand to withstand the large rotor downwash. The reference symbols and boards needed for Hover, Hover Turn and the Vertical MTE were made of aluminum. The symbols were painted red and mounted on poles, different colors marked the "desired" and "adequate" boundaries on the boards (Figure 5 a)). For the Landing MTE, marks were painted on one of the concrete circles in the dropping area, roughly representing ship landing marks (Figure 5 b)). The Pirouette course and performance boundaries were realized by plowing the ground (Figure 5 c)) around a concrete circle in the middle of the dropping area. Additionally a pole with a cone on top was put in the middle of the Pirouette course representing the height cue, see Figure 6. It was fixed with a barrel filled with sand and in addition was wired to the ground. The height and lateral position cues for the Vertical Maneuver MTE, consisting of reference symbols and boards for both heights, were mounted on two antenna towers located on the northeast end of the dropping area (Figure 7).

The first four-week phase of MTE flight testing began November 2004. This was the first time the MTEs were performed with the CH-53G. The objectives of this first phase therefore were to get initial feedback from the pilots regarding the ability to perform the MTEs with this aircraft, check the design and set-up of the ground courses, especially the visibility of the visual cues, and to identify necessary modifications. The data gathering phase started with collecting the quantitative data in May and April 2005. Four flights were needed, each lasting approximately 1.5 flight-hours. The HQR flights were performed in July and August 2005. Four pilots from WTD 61 and one U.S. pilot from NASA were involved, all of them experienced test pilots, but with different background regarding the flight hours on CH-53G. During each flight, the crew consisted of the evaluation pilot and co-pilot, two on-board crew members, and the flight test engineer. For external load operations, additional ground staff were needed. Every evaluation pilot flew a maneuver as often as needed to develop a repeatable control strategy before doing three evaluation runs. After performing the evaluation runs

Figure 4: CH-53G with 4000 kg external load.

a) Hover/Hover Turn



b) Landing

c) Pirouette

Figure 5: Examples of position cues.

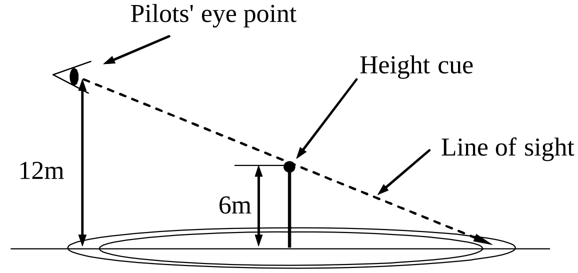


Figure 6: Pirouette height cue (schematic).

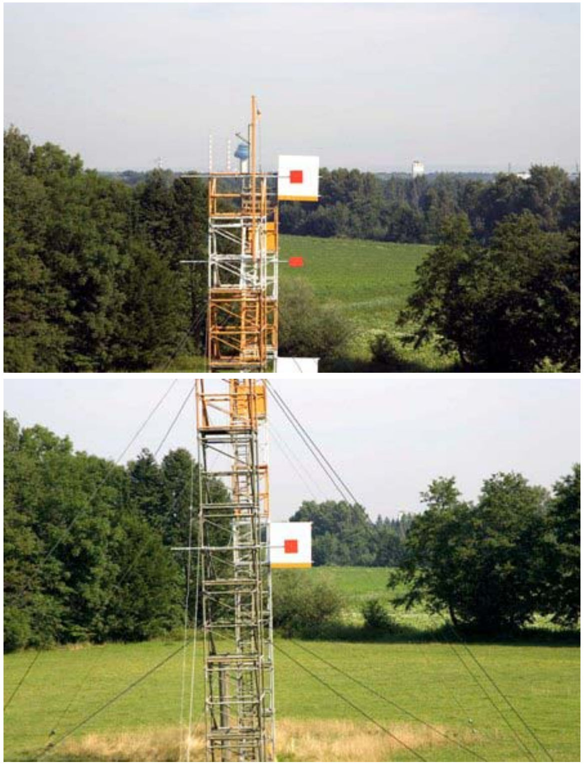


Figure 7: Vertical Maneuver cues.

the aircraft was landed on the cargo dropping area and the evaluation pilot filled in the questionnaire and gave his rating while the co-pilot had the controls. Having completed the questionnaire, the evaluation pilot took the controls again and the next MTE was approached.

RESULTS

MTE courses design

This section describes the set-up of the MTE courses, the cueing issues, and some MTE performance aspects observed from the piloted evaluations. In general, the courses were setup as suggested in ADS-33E. However, lessons learned from the CH-47D (Ref. 17 and 18) and the UH-60A (Ref. 12) assessments of ADS-33 were incorporated. During the initial course setup and pilot training for the CH-53G tests, it was noted that the aircraft is not typically flown below 25 ft unless the intention is to land. Consequently, all of the assessed MTEs were performed at higher altitudes than suggested in ADS-33E. To provide some margin of safety, the stationary MTEs were flown around 30 ft (radar altimeter) and the maneuvering MTEs were flown around 40 ft. Considering the 25 ft of load plus attachment, the external load maneuver height was set to 60 ft above the ground. The following paragraphs provide additional details and lessons learned on the cueing and performance aspects of pertinent MTEs.

Hover

The cueing for the Hover MTE was set-up as suggested in ADS-33E and as implemented in prior tests, such as with CH-47D, BO 105, and AH-64A. Following the piloted evaluations with CH-53G, two lessons learned emerge: with the hover board on the ground, precise altitude cueing is only available when the pilot-aircraft reach the final “desired” hover point; and fore-aft cueing is not as "rich" or equal to the strong lateral and altitude cueing from the hover board/reference symbol. Having the hover board on the ground, as opposed to being elevated to the pilot's eye height, does not provide precise altitude cueing during the translation along the 45-degree diagonal to the target hover point and therefore, can negatively influence the time to achieve a stabilized hover at the final “desired” hover point. As this time is one of the performance standards for assessing the “desired” or “adequate” performance of the maneuver, the overall handling quality rating for the maneuver can be influenced. Likewise, based upon pilot comments, the pilot workload associated with staying within the fore-aft tolerances at the final “desired” hover point appear to be influenced by the relatively poor fore-aft cueing (compared to the good lateral and altitude cueing from the hover boards). It is suggested that an additional hover board and reference symbol might be installed on the diagonal and/or on the side to try to improve the fore-aft cueing to be on par with the lateral and altitude cueing.

Hover Turn

The description of the Hovering Turn MTE is to perform a 180-degree turn from a stabilized hover while maintaining longitudinal and lateral position and altitude. During the CH-47D testing, initial experimentation with this maneuver involved turns about the aircraft center, the aircraft tail, and the pilot station. Following these iterations, it was decided that turning about the pilot station would be the most mission representative, although this turn-point would require cross-control inputs and would not allow evaluation of the aircraft's single-axis yaw response. For the CH-53G evaluation, after several similar iterations it was decided to do the Hovering Turn with a strategy closer to operational flying, i.e., mainly with pedal inputs, turning about a point behind the pilot station. With pure pedal inputs, the aircraft did not turn about the main rotor mast as initially expected, but a point somewhat in between the main rotor mast and the pilot station. The rotation point is an important issue for flight control designers and compliance testing organizations to consider as this is the reference point for assessing the position and altitude during the 180-degree turn. In addition, ADS-33 states the maneuver is to be performed in both directions. For rotorcraft with two pilot stations in a side-by-side seating arrangement, it is suggested that the evaluation pilot be allowed to fly the Hovering Turn from either seat to minimize the effects of cueing differences in the handling quality rating.

Lateral Reposition

The Lateral Reposition MTE is essentially a 400 ft sidestep maneuver. It is initiated from a hover and terminates in a hover. Although not stated in ADS-33E, the maneuver should be completed both to the right and to the left to assess any unsymmetrical coupling. And like the Hovering Turn and Pirouette, for rotorcraft with two pilot stations in a side-by-side seating arrangement, it is suggested that the evaluation pilot be allowed to fly the Lateral Reposition from either seat to minimize the effects of cueing differences in the handling quality rating. In addition, ADS-33E-PRF specifies to accelerate to approximately 35 knot ground speed during the maneuver, which is identical to the CH-53G limit for sideward velocity. It was found to be too aggressive for performing this maneuver and is not necessary for completion of the maneuver within the "desired" time constrains (18 sec, 25 sec with externally slung load). It is thus recommended to eliminate the 35 knot ground speed requirement from the description of the maneuver.

Depart / Abort

After the first discussion and test flights, the pilots commented that the loss of mainly lateral position cueing during the deceleration phase with high nose up attitudes made precise positioning at the end of the maneuver difficult. The ground course was therefore modified and set up at one end of one of the 2,000 m long straight roads in the dropping area, the aircraft now accelerating and decelerating with the road stretching out in front. This made the cueing satisfactory.

Vertical Maneuver

One of the main issues during this maneuver was the longitudinal position cueing which was found to be unsatisfactory. It consisted of traffic cones 90 degrees to the right and a line of traffic cones on a diagonal 45 degrees to the right. Height and lateral position cueing, from the combination of reference symbols and boards on the antenna towers, was judged to be very accurate by the pilots. It is recommended to define a minimum thrust margin for this maneuver in order not to influence the results too much by performance aspects. This is especially true for heavily loaded configurations, where reaching power/thrust limits increases the workload by the need to monitor the torque more precisely.

Pirouette

The Pirouette MTE requires the pilot to accomplish a lateral translation around the circumference of a 100 ft radius circle while keeping the nose of the aircraft pointed towards the center of the circle. The maneuver is to be terminated with a stabilized hover over a "desired" or "adequate" hover reference point after returning to the starting point. ADS-33E does not provide dimensions for these reference points. During the CH-53G testing, these reference points were defined to be a square based upon the defined "desired" and "adequate" tolerances for fore-aft positioning on the circumference of the circle. For example, the "desired" performance criteria states that the rotorcraft shall stay within ±10 ft of the circumference of circle. Hence, a 20 ft box was defined for the pilot to stop within at maneuver completion. Likewise, a 30 ft box was defined for "adequate." These were denoted to the pilots with traffic cones on the opposite side of circle, see Figure 5 c). During the performance of the maneuver, the "desired" altitude tolerance is defined to be ±3 ft whereas the "adequate" altitude tolerance is ±10 ft. This difference is more than three times and seems disproportionate with many of the other tasks, where a factor of two is more common. In addition, the ADS-33 states that the maneuver is to be flown in both directions. Like the Hovering Turn, for rotorcraft with two pilot stations in a side-by-side seating arrangement, it is suggested that the evaluation pilot be allowed to fly the Pirouette from either seat to minimize the effects of cueing differences in the handling quality rating.

Slalom

The Slalom MTE in ADS-33E is characterized by a series of turns around points or gates 500 ft apart longitudinally and offset 50 ft laterally from the centerline. The maneuver is to be flown at an altitude below 100 ft at an airspeed of at least 60 knots for "desired" performance and 40 knots for "adequate" performance. During the CH-47D testing, the maneuver was flown at light and heavy gross weights and, although the turn points were somewhat difficult to see at times, the aircraft performed satisfactory as long as the airspeed was maintained. From the CH-53G evaluations, the Slalom MTE as defined in the ADS-33E-PRF was found not to be suitable. "Desired" performance (min. 60 knots) could not be achieved and even "adequate" performance (min. 40 knots) was challenging. Turn coordination, engaged with feet on pedals above 60 knots, could not cope with the course. Subsequently, the longitudinal spacing between the gates was increased by 25 m, making it a moderate aggressive task (Figure 8). Now it could be performed to the "desired" performance standards. In addition, ADS-33E establishes forward flight (> 45 knot groundspeed) requirements in terms of airspeed, hence the Slalom MTE performance standards are based on airspeed. If the maneuver is performed on a windy day with either a headwind or tailwind, the perceived spacing between the gates can be quite different than on a calm day. To help standardize the maneuver, it is

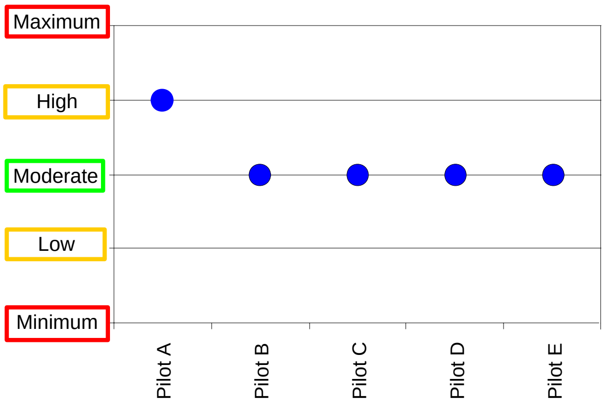


Figure 8. Aggressiveness rating of Slalom MTE.

suggested that the maneuver be evaluated on a calm day. If compliance testing is performed on a windy day, the speed performance requirements should be based on groundspeed and the course should be evaluated in both directions to help balance the aerodynamic effects. In addition, the maximum windspeed should be limited to low-to-moderate levels.

Slope Landing
The ADS-33E-PRF Slope Landing and the Landing MTE turned out to be not well defined and modifications were deemed necessary. At first it was not planned to take the Landing MTE into account, but to perform the Slope Landing MTE as described in ADS-33E-PRF as the only landing task. But after the first evaluation phase and based on pilots' comments, it was decided to separate the precision aspect from the Slope Landing task. The Landing MTE was thus put on the list of MTEs to be evaluated. During the first slope landings it turned out that the slope of 8.9 degrees left little to no lateral control margin when the down-slope landing gear was put to the ground and the collective was lowered. Because the landings to the sloped surface were performed close to the aircraft limit, the pilots' handling quality evaluations were highly influenced by monitoring the control margins. As a result, the increase in workload might turn out to produce higher ratings compared to what would have been returned if control margin monitoring would not be an issue. This was partly the case during the CH-53G evaluation. Based on this experience, it is recommended to also include a maximum slope value in percent (e.g., 90%) of the aircraft slope limit in ADS-33 besides the already defined minimum. Some other recommendations for the Slope Landing MTE include: eliminate the nose-down slope landing requirement; keeping the position requirement, but eliminate the requirement for a continuous descent to first contact with the slope; possibly retain a time to maintain a level rotorcraft attitude with one part of the landing gear in contact with the slope, but eliminate the "desired" and "adequate" performance numbers of 5 and 1 second respectively; remove the allowance for forward drift at touchdown in the "adequate" performance section; and require the maneuver to include full down collective with the main rotor parallel to the helicopter deck angle.

Landing
The Landing MTE in ADS-33E was originally spelled out in ADS-33A. The maneuver has evolved over the years in ADS-33 versions B, C, and D. The biggest change was from version C to D. Originally, the Landing MTE was characterized as a rapid vertical landing (completed within 6 seconds) to a space 3 ft larger than the helicopter's landing gear. In ADS-33D, based upon Army/NASA flight tests, the maneuver was changed from a rapid vertical landing to a more precise landing with more time to complete (10 seconds). The "desired" performance standards for touchdown were revised to ±0.5 ft (±15 cm) laterally and ±1.0 ft (±30 cm) longitudinally. These touchdown standards may be appropriate for a small helicopter, but for larger helicopters, like the CH-53G, these touchdown requirements seemed much too small. This impression was confirmed by the track data of the final evaluation flights, which is presented exemplarily for two pilots in Figure 9 and Figure 10. Although close several times, "desired" performance was never achieved. "Adequate" performance, ±3 ft laterally and longitudinally, was achievable. From the CH-47D testing, the pilots recommended that the performance constraints be changed to ±3 ft longitudinally and ±2 ft laterally within a designated endpoint. The results of the CH-53G tests support this. Nevertheless it is recommended that more development is needed on the Landing MTE for larger helicopters and consideration of shipboard landing requirements should be included in this process.

Pilot ratings (HQRs)
Figure 11 shows the Cooper-Harper Handling Qualities Ratings (HQR) for the internal load configuration for each MTE and Figure 12 for the external load MTEs, including the worst and best rating given as well as the mean value. Considering the mean values, the overall handling qualities rating is Level 2, although the large scatter of up to 5 HQRs present for some MTEs raises questions. Detailed information on the handling qualities ratings for those MTEs with a scatter larger than one HQRs will be given in the following paragraphs.

The analysis of the HQR scatter considered the following steps:

- Check, whether the wording of the given HQR according to the Cooper-Harper rating scale corresponds to the additional comments of the pilot (performance, workload).

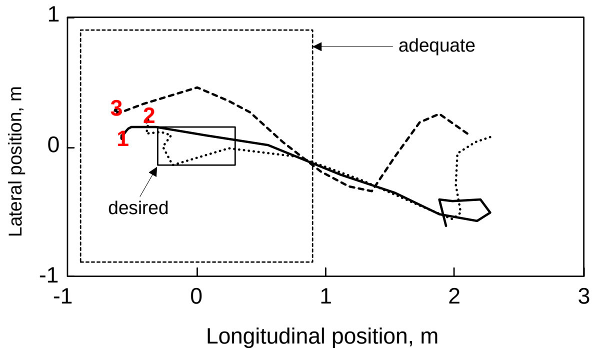


Figure 9: Pilot A Landing MTE tracks, three runs (internal load configuration; numbers: end position).

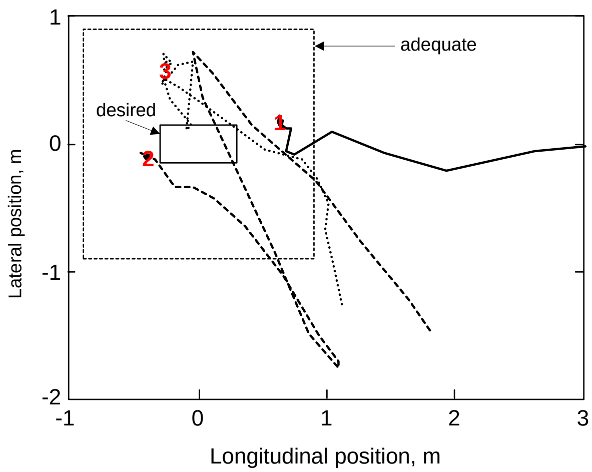


Figure 10: Pilot E Landing MTE tracks, three runs (internal load configuration; numbers: end position)

- If not, this needs to be clarified by discussion with the pilot.
- Check, whether the rated performance corresponds to the measured track data. Minor discrepancies are acceptable. But if there are striking differences (e.g. pilot rates "clearly within desired", but large parts of the measured track are outside desired or even adequate), influences on the given rating might have to be taken into account. Optimally the pilot should fly the maneuver again after being told to keep an eye on his performance. This might result in a different HQR, due to higher workload or because now the pilot is discovering some discrepancies in the axis he did not concentrate on in the previous MTE attempts.
- Check, whether the outside conditions (wind, cues, and visual conditions) and the aircraft configuration (mass, c.g., engaged AFCS functions) were the same throughout the MTE flights for all pilots.
- Check, whether all pilots approached the maneuver in the same way, compare strategy and aggressiveness, as well as control inputs used.

Depart/Abort

A scatter of 2 HQRs, from 3 to 5, is present. HQRs and pilot comments are all consistent, wind conditions had no influence. A general problem of all pilots was to identify the right point to begin the deceleration to come to a hover within the 20 ft "desired" box at the end of the maneuver. Another aspect mentioned was the noticeable loss in altitude when pulling longitudinal cyclic to decelerate. It is speculated that it was difficult for the pilot to judge the necessary collective inputs

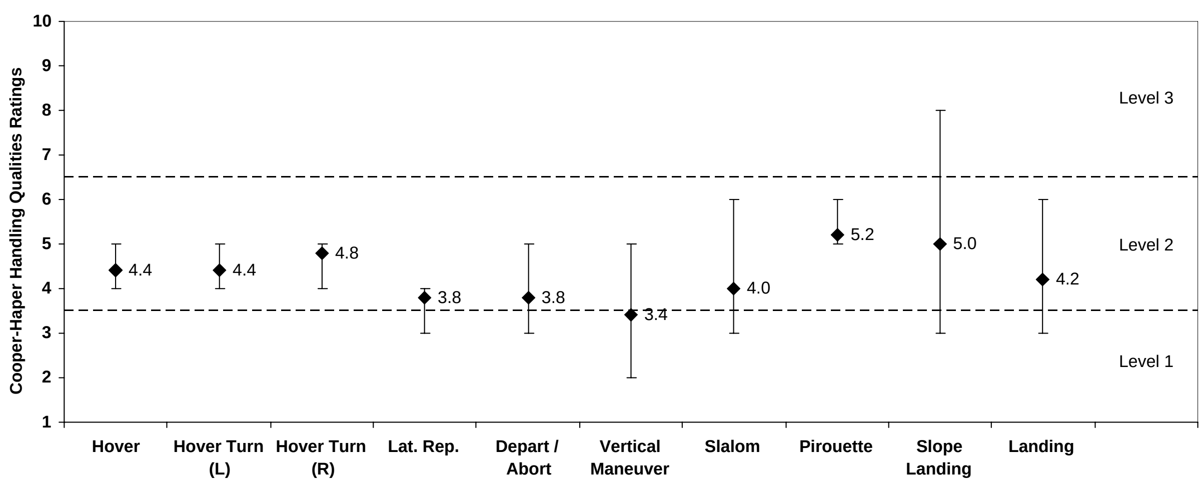


Figure 11: Cooper-Harper handling qualities ratings for the 34,000 lb internal load configuration (max., min., and mean ratings).

required to compensate for the altitude changes induced by the aggressive use of longitudinal cyclic in the deceleration. One pilot rated the necessary compensation as being considerable (HQR 5). The main driving factor for his HQR 5 was the achieved performance which he had the impression was never better than “adequate”, resulting in an HQR 5 according to the Cooper-Harper Rating Scale. But the track data shows that he was able to stay well within “desired”, although during two of the three attempts he was on the boundary of “desired” altitude (below 50 ft), see Figure 13. Based on this information, he changed his HQR to a 4, rating the compensation change from considerable to moderate as reasonable. This reduces the scatter to 1 rating.

Vertical Maneuver

A scatter of 3 HQRs, from 2 to 5, is present. The HQR 5 (pilot C) was mainly driven by the insufficient longitudinal position cues, resulting in only “adequate” or even out of “adequate” performance in this axis. Generally all pilots except pilot B, who gave the HQR 2, noticed the forward drift when descending that needed to be compensated with cyclic. But the control inputs and the track data of pilot B support his comment that this was a pure collective task. A comparison of the control inputs of pilot B and C reveals that the better performance in longitudinal position of pilot B was achieved with less activity in longitudinal cyclic, see Figure 14 and Figure 15. The data indicates that if the pilot gets into the loop to stabilize longitudinal position by introducing longitudinal cyclic inputs with a too high gain, things get even worse. Assuming this correlation the scatter of 3 ratings is not inconsistent, but reflects different approaches to the maneuver resulting in different amounts of workload and necessary compensation.

Slalom

A scatter of 3 HQRs, from 3 to 6, is present. Attempts to fly the task using the turn coordination feature without additional pedal inputs resulted in being out of track after the second of the four gates, not counting the ones at the beginning and end of the course. As a consequence the workload and thus the ratings were mainly driven by the effort to get through the last two gates. The pilots stated that if the course had additional gates (was longer) it was hardly possible to achieve even “adequate” performance. The pilot who gave the HQR 6 mentioned the high control forces as a negative influencing factor. In the debriefing session his piloting background with predominant BO 105 experience was identified as a possible driver for his impression of high control forces, which none of the other pilots agreed upon. But the main driver for the HQR 6 was the amount of workload, which the pilot rated as extensive.

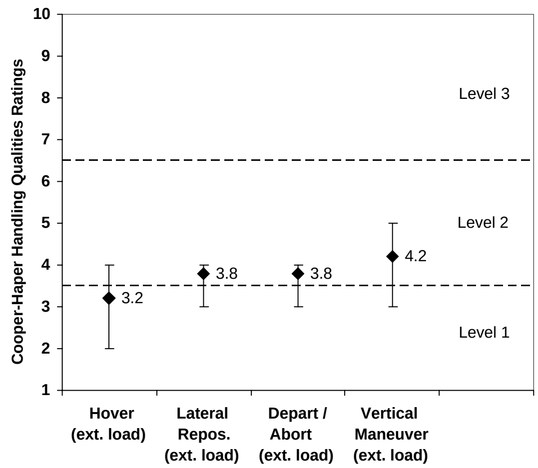


Figure 12: Cooper-Harper handling qualities ratings for the external load configuration (max., min., and mean ratings).

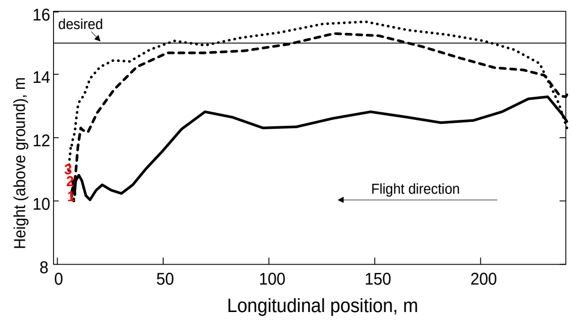


Figure 13: Pilot C Depart/Abort MTE tracks, three runs (internal load configuration; numbers: end position)

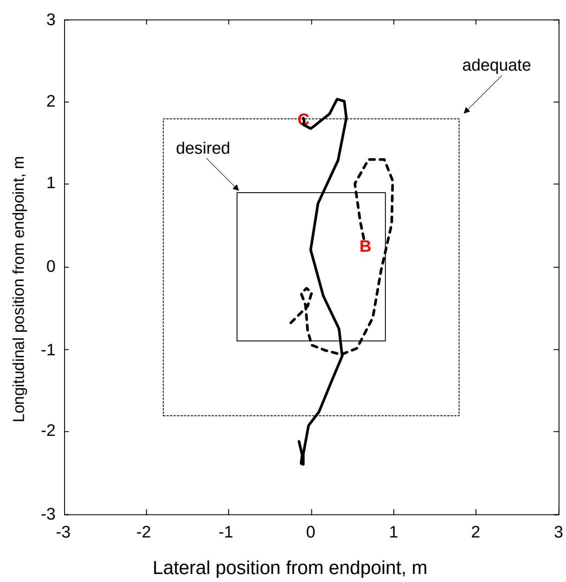


Figure 14: Pilot B (dashed) and pilot C (solid) track during Vertical Maneuver MTE (internal load configuration; letters: end of maneuver)

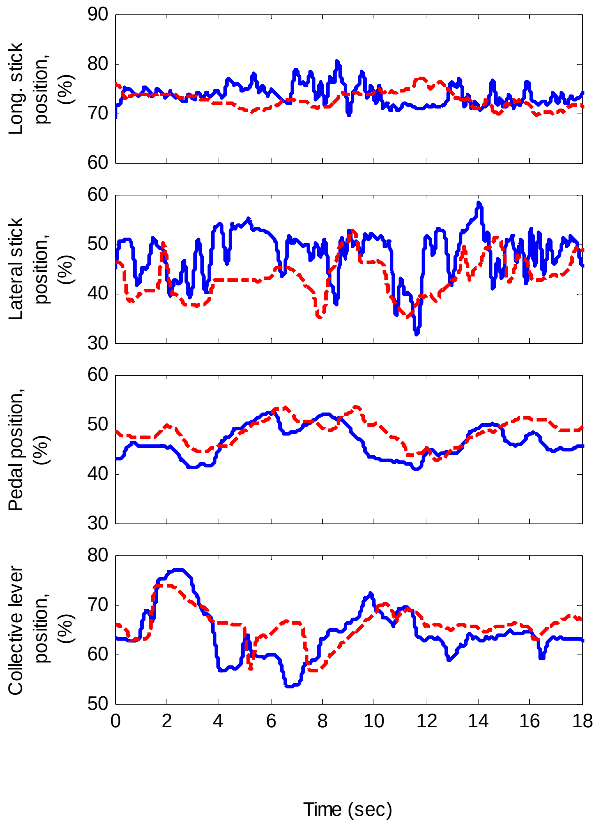


Figure 15: Control inputs during the Vertical Maneuver (internal load configuration; solid: pilot C, dashed: pilot B).

The track data shows that he achieved “desired” performance regarding the three constrains (track, speed and height). Since no repeating flight of the MTE was made, it was not possible to clarify whether the rating would have improved because of reduced workload if the goal was reduced to achieving “adequate” performance. The HQR 6, when averaged with two HQR 3s and two HQR 4s, drives the mean value to HQR 4.

Slope Landing

A large scatter of 5 HQRs, from 2 to 8 is present for this MTE. These are overall ratings summarizing the handling qualities impressions of the three different aircraft orientations with respect to the slope during landing. It is important to note that pilot C and E, who did the first evaluations of this MTE and returned the highest HQRs (see Figure 16), were the two pilots who flew the Slope Landing MTE during the flight phase in 2004, which was dedicated to get first impressions of the CH-53G flying the MTEs. Both pilots attended the corresponding debriefing sessions and gave their feedback. Pilot C, who was co-pilot during the other

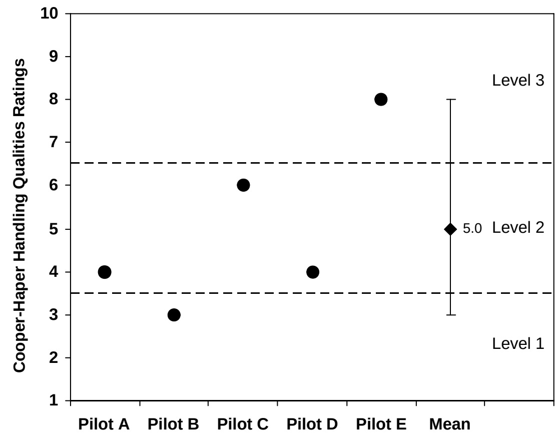


Figure 16: Individual pilot ratings for Slope Landing MTE (internal load configuration).

pilots’ evaluation flights, mentioned that he was surprised how easy pilot A, B, and D approached the task. While for him and pilot E the control margin aspect influenced the approach of the task and as a consequence their rating to a great extent, the other three pilots did not so much focus on the reduced margin, although they also mentioned it. Pilot B is the only one who returned an HQR 3. But he commented that except for the one wheel on the ground balance act the compensation required was minimal. This indicates that his rating does not cover this balancing act and that he might have returned a higher HQR if he was told to include this one wheel on the ground phase. Unfortunately this could not be clarified. Finally the mean HQR 5 seems to be a bit too high taking the two ratings into account that were mainly motivated by the control margin aspect.

Landing

A scatter of 3 HQRs, from 3 to 6 is present. Generally it must be mentioned that the pilots did not have cues for desired or adequate performance but a ship-landing-type of cue instead, see Figure 5 b). This was because of the uncertainty regarding the performance standards, as mentioned earlier. It was also discussed whether it is supposed to be a pure vertical landing or whether it is allowed to approach with a slight forward motion before putting the aircraft down. This forward motion is present in nearly all the track data and pilots stated that landing with forward motion is a preferred type of landing with the CH-53G. After some practice this maneuver was easy to perform for all pilots. Nevertheless the time limit of 10 sec to put the aircraft down influenced at least two of the ratings and drove those to higher values than could have been expected with more time to complete the maneuver.

Hover with external load
A scatter of 2 HQRs, from 2 to 4 is present. All of the pilots commented that the external slung load Hover MTE was easier to perform than the Hover MTE without the external load. Consequently all pilots rated this maneuver with one HQR better than the maneuver without load, except pilot B. He returned an HQR 2 compared to his HQR 4 without load. One of the primary influences was the doubling of the time to attain a stabilized hover with the external load compared to without the load. These results may raise a question about the appropriateness of twice the time to attain a stabilized hover with an external slung load.

Vertical Maneuver with external load
A scatter of 2 HQRs, from 3 to 5 is present. Four of the five pilots returned higher ratings for this MTE with the external load than without, see Figure 17. The main reason for this is the reduced power margin, that makes more precise and cautious collective control inputs necessary, thus the time constraint now becomes a factor. It should be noted that the overall aircraft weight (including the external load) was 4,800 lb more than the internal ballast configuration. Pilot A returned HQR 5 mainly because of the bad cues for longitudinal positioning (see earlier discussion of results for the Vertical Maneuver MTE without load). The other HQR 5 (pilot E) was influenced by the gusty 11 kt wind 65 degrees from the left, requiring considerable compensation in the lateral axis. The pilot could hardly make the maneuver in desired time in this wind condition. The other pilots had only 2 to 4 kt of wind. In addition he experienced a vertical PIO in the second run, which he rated separately as HQR 8.

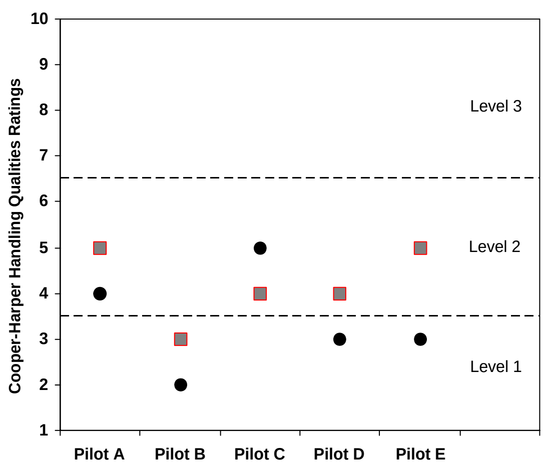


Figure 17: Individual pilot ratings for Vertical Maneuver MTE (dots: internal load, squares: external load).

CONCLUSION

Generally the altitudes for performing the MTE evaluations were increased by 15-20 ft for this size helicopter. The time/tolerances experienced were borderline desired/adequate or adequate.

MTE specific conclusions:

Hover
The fore/aft cueing at the final hover position are important. It is proposed to provide a second hover board for the fore/aft positioning.

Hover Turn
The CH-53G turns were initiated with mainly pedal inputs, turning about a point between cockpit and rotor mast. This was based on pilot feedback and was believed to represent a more operational procedure. ADS-33 should specify the point of rotation, or mention to initiate the maneuver with mainly pedal inputs.

Lateral Reposition
ADS-33 specifies to accelerate laterally to 35 knots. It is proposed to delete this speed requirement from the maneuver description. The option to evaluate this maneuver either from the right or left seat in a side-by-side cockpit should be given.

Depart/Abort
The main issue for the pilots was to identify the point where to start the deceleration. This influence could be reduced by providing an additional cue.

Vertical Maneuver
The reduced power margin when performing this task with a slung load was a major issue. ADS-33 should account for different thrust margins.

Slalom
Increasing the distance of the gates resulted in a moderate aggressive maneuver. It is proposed to state in ADS-33 that the maneuver should be flown on a calm day and to change the speed requirement from airspeed to ground speed. In addition, it has to be further clarified whether a cargo helicopter of the size of a CH-53 or CH-47 should be able to fly as aggressive as specified in ADS-33 by defining the given ground course.

Pirouette
Lateral position cues for the final hover position were added to the course. For a side by side cockpit the option of evaluation from right and left seat should be given.

Slope landing
The ADS-33E description needs to be refined:
- the position and time requirements need revising
- the nose-down landing should possibly be eliminated
- the maximum test slope should be set to 90% of the helicopter design capability

- it should be required to reach full down collective and the main rotor parallel with the helicopter deck angle.

Landing Task
The desired performance standards for the final position as listed in ADS-33E-PRF could not be achieved. It is recommended to adopt the recommendations from the CH-47D tests. For further development of this task, ship landing requirements should be taken into account.

Even though ADS-33 is a significant improvement over the old MIL-H-8501, based upon the evaluation with the CH-53G, it will still need to be reviewed and tailored for a specific helicopter procurement, especially for configurations different than those for which it was originally developed.

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Figure 18 shows part of the U.S.-German team after a successful test including participants of WTD 61, AFDD, NASA, and DLR.

Figure 18: Part of the U.S./German team after a successful test.

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