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EXPLOITING A FLIGHT TEST MANEUVER FOR THE NH-90 HELICOPTER. DEFINITION OF A TEST COURSE WITHIN THE REQUIREMENTS OF THE ADS-33

BY

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"EXPLOITING A FLIGHT TEST MANEUVER FOR THE NH-90 HELICOPTER. DEFINITION OF A TEST COURSE WITHIN THE REQUIREMENTS OF THE ADS-33"

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1. Abstract

The pull-up/push-over Flight Test Maneuver described in the Aeronautical Design Standard 33 dedicated to Fly-By-Wire helicopters handling qualities design and evaluation lacked the necessary details to allow a rigorous evaluation of the NH-90.

Flying a similar class Sikorsky HH-3F, the Italian Official Test Center developed a "test course" that helped finding exact maneuver parameters, tuning pilot aggressiveness and setting the different levels of task performance therefore allowing the repeatability necessary for results' consistency.

The findings proved the validity of the new assumptions and led to the awareness that the Cooper & Harper methodology requires a rigorous approach, a flexible attitude towards theoretical description of evaluation parameters and flight test validation.

This new set of mind appears helpful to avoid underestimation of deficiencies and gross rating scatter in the evaluation of handling qualities.

2. Notations

ADS	Aeronautical Design Standard
AFCS	Automatic Flight Control System
AWR	Air Worthiness Release
CHR	Cooper Harper Rating
CSAR	Combat Search and Rescue
DAO	Divided Attention Operation
DVE	Degraded Visual Environment
FBW	Fly By Wire
FCS	Flight Control System
FTM	Flight Test Maneuver
HMSD	Helmet Mounted Sight Display
HQ	Handling Qualities
IMC	Instrumental Meteorological Conditions
MCP	Maximum Continuous Power
MTE	Mission Task Element
NAHEMA	NATO HElicopter Management Agency
NFH	Naval Frigate Helicopter
NOE	Nap Of the Earth
OFE	Operational Flight Envelope
OTC	Official Test Center
PFCS	Primary Flight Control System
SAR	Search And Rescue
SCAS	Stability & Control Augmentation System
RCAH	Rate Command Attitude Hold
TTH	Tactical Transport Helicopter
UCE	Usable Cues Environment
WSDS	Weapon System Development Specification

3. Introduction

The NH-90 helicopter is a joint quadrinational effort involving Italian Agusta, Eurocopter France, Eurocopter Deutschland and the Dutch Fokker.

The rotorcraft is a twin engine with two engine versions (RTM-322 or GE T-700, 1850 SHP), multi-role, four blade main rotor head, 9-ton class helicopter and is developed in a naval anti-submarine/anti-surface unit warfare version (NFH) and in a troops transportation army version (TTH). A dedicated Combat SAR (CSAR) version, derived from TTH, is under study for acquisition by the Italian and German Air Forces.

All versions have been conceived incorporating the most innovative technical and technological solutions in order to fulfill all mission requirements in all weather and modern warfare environmental conditions. Figure 1 in annex shows a photograph of prototype No. 1 (PT1).

In order to achieve the required Level 1 Handling Qualities (HQ) within the Operational Flight Envelope (OFE), the NH-90 is fitted with a full authority FBW flight control system, unique for this helicopter class.

The flight control system consists of a quad-redundant digital architecture, with no mechanical back-up (but for some of the development rotorcraft) and it is based on two main subsystems: the Primary Flight Control System (PFCS) and the Automatic Flight Control System (AFCS).

The PFCS provides control and stability augmentation functions. Three "piloting" modes are selectable:

- the SCAS mode provides rate command type response and is capable of basic stability and control augmentation, plus "ball centering" or zero yaw rate command depending on the flight regime;

- the ATT (Attitude) mode, specifically designed to be the nominal mode and to grant Level 1 HQ in IMC or DVE, provides RCAH type response plus "ball centering" in forward flight and heading hold in hover;
- the TAC (Tactical) mode provides, in the short term, the same functions as the ATT mode. An "auto-trim" feature is incorporated allowing control force feed-back to be present while maneuvering but to be automatically zeroed out as a function of helicopter flight regime. This mode has been specifically designed for NOE/Contour Flight operations but is not recommended in DAO or DVE conditions.

Shown aside are the front, side and top views of the helicopter.
The PFCS allows continuation of flight after a system failure in various modes of operations. Total loss of the digital quad-redundancy is backed-up by a flight control degraded mode based on an analog computers structure.
The Aeronautical Design Standard 33, developed for the U.S. Army "LH" program and extensively used in what had become the RAH-66 Comanche (first full FBW rotorcraft), has been agreed for use as a design guideline for the NH-90 handling qualities (Ref. 1).
The ADS-33 was intended to be a revision of the MIL-H-8501A specification, issued in 1962, that had obviously become obsolete.

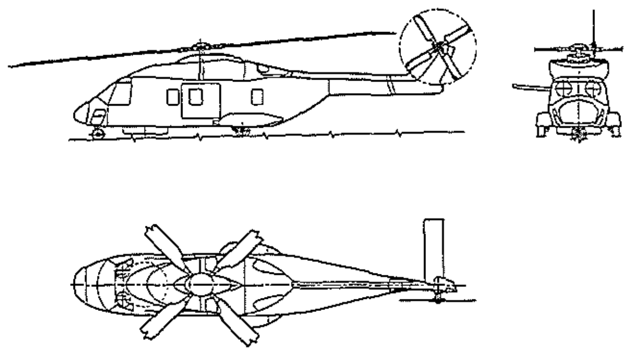

Figure 2: NH-90

This new document not only provides engineering performance requirements defined in terms of new criteria such as Band Width and Phase Delay, but also provides mission-oriented requirements. In this contest, some new concepts are presented in the document, including "Mission Task Element" (MTE) and "Usable Cues Environment" (UCE). The ADS-33 from the first issue to the D version, latest 1994 release of the document, defines requirements for scout, attack and utility type rotorcraft.
Therefore, in 1993 the "ADS-33 Tailoring Ad Hoc Group" was created in order to adapt and implement the document requirements to the TTH and NFH missions. The working group, supervised by NAHEMA, is composed by test pilots, engineers and experts from the four Nations' official test centers (OTC), research establishments and Industries. Works have been momentarily suspended (whilst the flight control system completed the early development phase) and will be resumed in order to support flight test as soon as the final development and certification phase begins.

The Tailored ADS-33 is divided into three parts:
- Part 1 "Definitions and General Assumptions" is comprehensive of the ADS-33 sections 1 (Scope and Compliance) and 3.1 (General Requirements). It includes definitions and general assumptions which will be used to support NH-90 FCS design. Part 1 also contains the definition of the OFE's for the two versions of the helicopter and the definitions of the MTE's to be used in the HQ assessment.
- Part 2 "Quantitative Criteria" contains the ADS-33 sections 3.2 through 3.9 and describes "response types" and quantitative criteria (controllers' characteristics, bandwidth, phase delay, etc.).
- Part 3 "Flight Test Maneuvers" is the equivalent of the ADS-33 Section 4. It contains the selected FTM's which will be used for demonstration of HQ and describes the method of evaluation.

The tailoring process obviously considered and manipulated both the engineering aspects and requirements contained in Part 2 of the specification and the aspects related to the mission contained in Part 3. This paper will deal with a specific problem encountered in one of the FTM's listed in this last part of the ADS-33.

4. Problem Origin

The ADS-33C is specifically based on the Cooper & Harper theory relative to aircraft handling qualities evaluation and rating (Ref. 2).
This theory classifies the handling qualities of a given flight test maneuver by the use of a rating scale (Table 1 in Annex) which ranges from 1 to 10 and which correlates the achievement of the performance with the relative pilot workload. The Cooper & Harper methodology is strictly dependant on a clear definition of aircraft "role", "mission" and mission "segments". Accomplishments of the mission is strictly dependant on the satisfactory achievement of the "tasks" required to the pilot. Satisfaction is defined as the attainment of a "desired" or "adequate" performance of the man-machine system.
The main question was the adaptation of what had been conceived for an attack, agile and light rotorcraft to a heavy, transport machine; not only in terms of mission and definition of mission tasks (noted as Mission Task Elements in the ADS) but especially in terms of parameters and performances minima for the accomplishment

of the Flight Test Maneuvers derived from those MTE's. The initial approach has been to suppress some of the FTM described in the original document (generally those calling for weapons delivery capabilities).
However, a precise requirement of the NH-90 development contract (WSDS) for the TTH version was to be able to perform Nap-Of-the-Earth (NOE) and Contour Flight. It was therefore decided to keep one of the critical FTM's amongst those listed in the original ADS which were susceptible of being scraped off: the "Pull-up/Pushover", which relative MTE corresponds to an obstacle avoidance high speed type maneuver performed during the Contour Flight part of the sortie.

Infact, the Pull-up/Push-over FTM main objective, as reported in the original ADS-33, *is to evaluate the Handling Qualities of the helicopter at elevated and reduced load factors and during the transitions from considerably high values of load factor to considerably low ones and vice versa.* Additional objectives are *to assess inter-axis coupling and the ability to avoid obstacles during high-speed NOE operations.*
These objectives clearly refer to an air combat capable rotorcraft. However, the last one has relevance for transport helicopters with "Contour Flight" capabilities (which are indicated as "high speed NOE" operations, even if a strictly rigorous definition of NOE implies low speed and extremely low altitudes).
The initial tailoring of this FTM only took into account a relaxation of the tolerances (adequate and desired performances) to fit them to the NH-90, accepting the given description of the maneuver and the lack of a test course, which are instead foreseen for all the other FTM's. Furthermore, examining the maneuver description, it appeared that some of the performance required (i.e. load factor control) were information about aggressiveness, pertaining more to a maneuver description than to a tolerance matrix.
Even accepting to maintain unvaried the objectives and their order in the tailored document, further exploitation was mandatory to make the FTM repeatable, reproducible, compatible with a Cooper & Harper methodology and adherent to the real characteristics of the relative MTE. These requirements were also mentioned by C.J. Ockier in his research on ADS-33 conducted with the BO-105 helicopter (Ref. 3).
The Pull-up/Push-over FTM description of the original ADS-33 is as follows: *From level unaccelerated flight at 120 knots, or with maximum continuous power, whichever results in the lowest power, attain a sustained positive load factor in a symmetrical pull-up. Transition, via a symmetrical push-over, to a sustained negative load factor and recover to the initial air speed as rapidly as possible.*
The desired performance statement reports: *Attain a normal load factor of at least the positive limit of the OFE [$n_L(+)$] within 1 second from the initial control input. Maintain at least $n_L(+)$ for at least 2 seconds. Accomplish transition from the positive $n_L(+)$ pull-up to a push-over of no greater than the negative normal load factor limit of the OFE [$n_L(-)$] within 2 seconds. Maintain a load factor no greater than $n_L(-)$ for at least 2 seconds. Maintain angular deviations in roll and yaw within ±10 degrees from the initial unaccelerated level flight condition to completion of the maneuver.*
The adequate performance differs from the desired only for a higher (±15°) angular deviation in the roll and yaw axes motions.

Many objections can be made. Principally, the maneuver, as described, is missing the necessary details and parameters. More specifically:
- it is missing specific reference to aggressiveness (only partially retrievable by the performance statements);
- the performance requirements are mainly expressed in terms of undesired cross-coupling related helicopter motions and not in terms of task accomplishment;
- the longitudinal performance is presented rather as an instrument flight parameter acquisition than a pilot-in-the-loop like task;
- the absence of a test course prevents an adequate UCE (intending for UCE the sum of available internal and external sensorial information enabling the pilot to fly and measure discrepancy from the required performance).

The FTM above described looked more as an engineering test maneuver rather than a mission task related HQ assessment tool. It appeared, and it was later confirmed, impossible to grant repeatability, thus not allowing the use of the Cooper & Harper methodology.
J.A. Ham & C.P. Butler also discovered a problem with the lack of spatial constraints in the pull-up/pushover FTM during their study on the AH-64 Apache handling qualities, applying the ADS-33 criteria (Ref. 4).

Another consideration was that the NH-90 program involves pilots from several European armed forces with specific backgrounds and training curricula. Therefore differences in pilot control strategy or flying techniques had to be expected to further decrease CHR consistency, thus affecting identification of potential HQ deficiencies. Aggressiveness control through a precise maneuver description and test course design was considered to be mandatory to reduce a potential additional scatter in the CHR.
During the development phase of the PFCS a large use of fix-base simulator was made. These sessions helped in validation of test courses, in tuning performance criteria through analysis of CHR coming from different pilots and in verification of control laws for all the selected FTM's.

But since no test course was foreseen for the pull-up-pushover, no such a maneuver was tested in a simulation environment. And, as said before, too many assumptions would have been required.
Flight test appeared to be the way with the most valuable returns.

5. The Approach

The Italian NH-90 team from the Air Force OTC, Reparto Sperimentale Volo (RSV), took over the challenge.
The solution of this problem could have taken two main directions: the implementation of an electro-optic gimmick capable of giving the pilot precise command guidance and deviation from performance; or the creation of a "hardware" scenario granting the same information in a more "natural" way.
The first one was going to be too expensive and it could have been argued that such a technique could be implemented through simulation only (although needing to cope with many assumptions such as Nz feedback, aggressiveness and task performance accomplishment).
The second one, although the most effective, implied a non-negligible flight safety issue and a definitely demanding solution.

It was therefore decided to follow an empiric way starting from the FTM as described in the original ADS with the scope of tailoring the desired and adequate performance to the NH-90. Should flight test have identified areas of possible weakness in the original assumptions, then the idea was to proceed step-by-step in setting new assumptions and in developing and adapting a test course accordingly.
Right here was the biggest obstacle to the "flight" option: the creation of the test course, that is a usable cues environment and specific test conditions capable of granting adequate pilot feed back throughout the maneuver, thus closing the man-machine-results loop.
No maneuver can ever allow Cooper & Harper ratings if the pilot is kept out of the loop.

6. The Test Helicopter

Keeping in mind the basic features of the NH-90, particular attention was devolved in ensuring a similar helicopter so that flight test would produce usable results for the same class helicopter.
The HH-3F is an 8 ton class helicopter, powered by two 1500 SHP turbine engines equipped with fully articulated 5 blades rotor head and with conventional "swash plate"-type, hydraulic actuated flight control system. This helicopter is used in the SAR and CSAR role by the Italian Air Force.
Shown aside are the front, side and top views of the helicopter.
Besides the slightly bigger dimensions of the HH-3F with respect to the NH-90, some other peculiarities can be noted: the NH-90 blade tip speed is 5% higher than the HH-3F's; the HH-3F's referred Disk Loading (Ct/σ) value, considered at respective maximum takeoff weights, sea level ISA conditions, is 8.2% lower than the NH-90's.
Table 2 in Annex shows a comparison between some HH-3F and NH-90 characteristics. The "focal distance" is a parameter related to the helicopter pitch control moment magnitude and sensitivity, typically calculated for a hover condition. Theoretical results show that the NH-90 control power is higher than the HH-3F's. This information was used by the test team to validate HH-3F data.

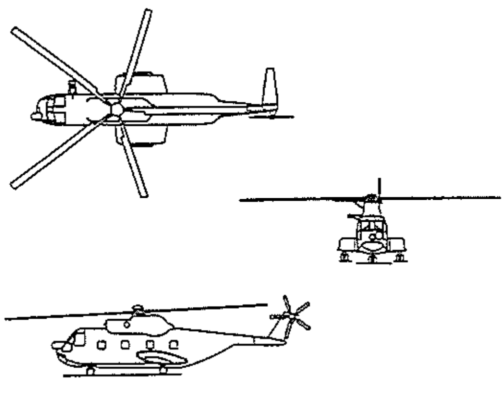

Figure 3: HH-3F

Table 3 in Annex shows a comparison of disk loading values between HH-3F at test conditions and both versions of NH-90 at respective mission reference conditions. From these values it can be noticed that NH-90 has generally higher disk loading values with respect to HH-3F.
The data highlighted that, because of difference in technology between the two helicopters, NH-90 develops higher disk loading values and displays better control power with respect to HH-3F.
Within the scope of the test, the above mentioned differences do not affect results significantly.

7. Flight Test Activity

7.1 Phase 1

Initial flights were performed following the ADS-33 definition of the pull-up/pushover FTM which considers the piloting of Nz peaks and duration.

This was performed using different pilot techniques and/or aggressiveness, although none of these factors were defined in the maneuver description. Results in term of helicopter trajectory were therefore largely different from pilot to pilot.
It has to be noticed that to avoid the introduction of other factors of variability such as the rotor response to collective changes, it was decided to perform the runs in a fixed collective angle condition.
Mainly three trajectory-referred points can identify a typical maneuver: an initial entry point, a top point and an exit point.
Figure 4 in Annex, directly taken from one of the typical run telemetry sheets, shows the helicopter trajectory and ground speeds expressed in Knots.
The flights were performed in a 20 kts steady head-wind component, therefore the values had to be corrected in order to refer data to a no wind condition.
Concerning the selection of the maneuver entry speed, the HQ qualification requirements of the WSDS include the need of performing aggressive tasks (such as the pull-up/push-over) at high power settings (power margin down to 17%). Being the power required for the original 120 KIAS too far from the WSDS recommended values, it was decided to use 130 KIAS which corresponded to a much higher power required, thus allowing a more representative margin.
Same results, supported by additional maneuvering requirements, were found during the ADS-33 tests conducted on the Apache which led to use of MCP for this specific FTM.

Each pilot performed three training passages to accustom himself to flying the helicopter in such a particular test environment. Even after sufficient training, the results showed large trajectory deviations amongst the numerous runs performed by the three pilots involved. Discussion brought up that the factor mostly affecting such a large spread of results was the technique of achieving and maintaining the required load factor.
Finally it was discovered that "piloting" the Nz did not provide the pilot good exterior cues, thus impeding the control of the trajectory of the helicopter and its axis cross-couplings.
Another interesting side result was that maintaining the collective pitch fixed caused an apparent helicopter inertia that led to a sluggish response in the longitudinal axis, especially during the pushover phase. This led to the conclusion that the collective pitch had to be used as necessary within the achievement of the task.

The problems encountered could have been partially mitigated by relaxation of the original requirements contained in the original ADS-33. Obviously, this approach would have been nevertheless wrong and, besides diminishing the value of flight test, it would have degraded the capabilities to encounter dangerous HQ deficiencies of the NH-90 when in high-speed longitudinal dynamic maneuvers.
The question was discussed and decision was made to reconsider and exploit the original operational need of the maneuver: being the Contour Flight a Fully Attended Operation, no distraction could be allowed to read and "fly" typically head-down displayed information such as load factor (Nz) or airspeed, at least before the implementation of a dedicated head-up symbology (HMSD).
It was therefore decided to proceed with the creation of a simulated obstacle that could offer adequate visual cues to pilot, at least in the ascending part of the maneuver.
The Nz had to be only considered as a safety-related parameter to be monitored to remain within the OFE.
In this respect, dedicated flights helped verifying the relationship amongst airspeed, aggressiveness and helicopter dynamics in order to avoid surprises in the test theater.

7.2 Phase 2

From analysis and discussion of Phase 1 flight activity it became immediately evident that it was necessary to give the evaluating pilot enough features to generate an environment of usable visual cues. The first step was to provide an elevated aim feature.
Initial study considered an old control tower on the side of the main runway at Pratica di Mare airfield, but theoretical trajectory analysis discarded it as unfeasible both for its limited vertical dimensions and for the safety issues related to the descending part of the maneuver.
One of the easiest and quickest solutions to the problem was the use of an airborne target as a helicopter in a ground-referenced hover. A Nardi-Hughes NH-500E of the Italian OTC, equipped with a radio-altimeter, was selected as target helicopter.
It was positioned at a height of 500 ft to keep it in the safe zone of the "H-V" diagram. The old tower was selected to be the starting point of the new course.
It was now necessary to define "flyable" parameters to allow the pilot to appreciate deviations and therefore to measure workload.
Aggressiveness would have been determined by appropriate positioning of the "obstacle" with respect to the starting point. This would have finally determined "trajectory constraints" that matched the real MTE. Time required to reach the top of the maneuver was also considered as a parameter to force pilot into the right set of mind. Lately it was found that also this parameter was a fall-out of the trajectory and entrance airspeed and therefore not significant for a performance matrix.

A great attention was dedicated to the aggressiveness issue. It was infact noted that the "simulation" environment often induced the evaluating pilot to be either too aggressive or not aggressive enough.
Where the first tendency manifested fictious high workload requirements, the second risked not pushing the man-machine gain to a point where a problem showed up. A good example is the JAS 39 Gripen accident related to a high gain task (landing in moderate turbulence) that caused a yaw-to-roll coupling never evidenced during simulations or early tests (Ref. 5).
The key word was realism, and that's where a good test course and a good description had to lead.

Some of the preliminary ADS objectives were left unaltered, such as the attitude max deviations, even though they were not relevant to the quality of results. On the other hand some parameters relative to the distance from the obstacle were necessary. The initial reticule around the target was set in two concentric circles of 10 meters for desired and 20 meters for adequate performance. This performance was monitored by an operator on the hovering helicopter estimating distances with the help of a rudimental hand-held graphic sight for real time report to the pilot and, later, by trajectography results for test point validation.
Using the experience of Phase 1 tests, decision was taken to fly the maneuver using all flight controls, including collective pitch. No other special pilot technique was required to reach the "obstacle". Preliminary up and away assessment helped the test team to verify the rotorcraft envelope, giving confidence about the remote possibility of over-stressing the helicopter when maneuvering in those conditions.
The test course (figure 5 in Annex) was quite simple: the starting point was ground referenced, the top point was the NH500 and the exit point was defined as the return of the airspeed to the starting value (as also required by the ADS-33 original maneuver definition).
This methodology started showing better results in terms of helicopter attitude control (correction of axis coupling motions) and flight task realism.
As usual, the first set of runs in the new test course were dedicated to pilot build-up and, again, to check for any limitation or control margins. Looking out for the target allowed the pilots to constantly stay in the loop thus permitting a considerably more precise control of trajectory than experienced in the previous phase.
However, trajectories resulted still very different one another, as also aggressiveness appeared to be different from pilot to pilot, throughout the maneuver. After an examination of the flight data, it was found that similar results were achieved with similar distances between the starting point and the target. This meant that the starting point had to be a key factor in determining pilot aggressiveness, and even a small difference in terms of distance between the starting and the aim point appeared to be causing a large difference in workload required to the pilot.
The inconsistency of pilots in determining the starting point was lately discovered to be depending on the height of the helicopter (500 ft) when passing abeam the starting reference point. At that distance, at such airspeeds, position in space was not easy to be judged precisely. Therefore it was decided to give pilots a little help: leaving the old control tower structure to allow positioning but announcing the exact starting position from the telemetry room.
This definitely improved the trajectory scatter giving good confidence of consistency.

The second big consistency problem was related to the trajectory described in the descending part of the maneuver.
Original description required the crew to maintain a predetermined load factor until the acquisition of the entry airspeed but this caused extremely large scatter in time necessary to reach the entry speed, in pilot workload and in final pitch attitudes.
As also discovered, during tests conducted on the Apache, the original ADS requirements caused extreme pitch down attitudes well beyond the Air Worthiness Release (AWR) limits for the helicopter and completely unrealistic.
This made them come to the conclusion that the maneuver had to be changed not to exceed limitations, even though no solution was found to relieve pilot from the additional workload required by monitoring the helicopter systems during such a demanding task.
Going back to the NH-90 flights, it was now clear that the original definition of the second part of the maneuver, again, was keeping the pilot out of the loop, that is, requiring him to fly referring to head-down parameters, without feedback from outside cues and attitude response of the rotorcraft. A situation similar to the one encountered for the first part of the maneuver.
Also in this case, the problem was solved trying to refer the MTE to the real mission as closely as possible. This required redesigning the second half of the test course.
Flight test results so far obtained indicated that the pitch attitude attained in the descending part after reaching the top was the factor that mostly affected the whole trajectory.
The operational pilot, after reaching the top of a natural obstacle, flies the helicopter in the intent to resume original height as quickly as possible, pointing to a "future" aim point that enables him to match the contour of the terrain thereafter. The position of this future imaginary aim point depends on pilot aggressiveness.
The airspeed had to be a fall-out determined by the helicopter kinematics, given the correct positioning at the top of the hill.

An external visual cue was therefore positioned on the ground (a truck on the side of the runway) so that, when acquired by the pilot abeam the target, it could determine a 20° nose down trajectory. This would definitely set a standard for aggressiveness. Maneuver would end reaching the entry airspeed (exit point).

7.3 Phase 3

The OTC crew flew a final set of flights with the new definition of entry, top and exit points.
Time necessary to reach the target and to reach the exit point was measured during each run performed. At the same points attitude, airspeed and other parameters were also taken. Performance was therefore measured in terms of circular position error around the top of the target, in terms of workload during pull-up (control of couplings and loaded rotorcraft response) and trajectory control at low Nz. The results are shown in table 4 of Annex. Figure 6 in Annex details the results achieved directly on the test course.

Figure aside sketches the performance achieved in terms of circular error around the airborne target.

After the analysis of the third phase test results it turned out that some key parameters (minimum and maximum Nz, airspeed at top, time to reach top and exit points, pitch attitude during pull-up and push-over) tended to repeat themselves in value, consistently with the test course parameters (distances and heights of starting, aiming and finish points).
These results implied that the FTM performed following this new test course was repetitive and allowed different pilots to make comparable assessments and to use comparable levels of aggressiveness.
The achievement of desired or adequate performance in terms of circular error from the "obstacle" proved to be able to modify workload. Furthermore, the respect of the allowed attitude limitations was also part of the performance needs in the completion of the maneuver.
In order to adopt simplified hypothesis, no vertical wind component was assumed. Since all the distances measured were ground referenced, they had to be modified taking into account longitudinal wind components. No explicit mention to it is made in the maneuver description but the recommendation to perform the FTM in calm wind conditions implies the use of a correcting algorithm.

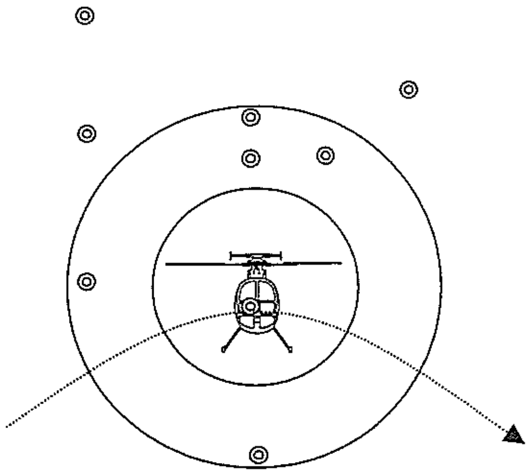

Figure 7: HH-3F phase 3 trials.

Inner circle: desired performance;
Outer circle: adequate performance.

8. Tailored Test Course

Although a great effort was dedicated to extrapolate NH-90 kinematics characteristics from HH-3F flight test data, reserves were raised by specialists of the four nations composing the NH90 ADS-33 tailoring working group about freezing exact course parameters before qualification of the FBW system on prototypes.
Therefore, "TBD's" were proposed while awaiting for further development of NH-90 FCS. Values will be defined, starting from HH-3F results, to ensure the achievement of maximum and minimum load factors as defined in the OFE.
Normal load factor experimented with HH-3F flight tests was maximum 1.6 g and minimum 0.6 g. Taking into account NH-90 OFE with TTH and NFH reference mission, normal load factors of 1.7 g maximum and 0.5 g minimum are indicated for 130 TAS. As it can be seen, these values are not significantly different from HH-3F ones, so we can expect that also longitudinal and vertical distances will remain similar.
For ADS-33 tailoring purposes, NH90 desired and adequate performances values are those used for the HH-3F, with the only difference that the allowable distance from the target helicopter is expressed in rectangular windows (more representative of the operational need of passing on the top of an hill) rather than circles. This decision was based upon the fact that NH-90 should demonstrate at least the same performance values of a similar class helicopter as HH-3F.

Finally, below is reported the new Part 3 paragraph of the ADS-33 relative to the pull-up/push-over FTM:
The maneuver is initiated in a level unaccelerated flight at 130 KIAS and at a height of 500 ft. The pilot should aggressively maneuver the helicopter to pass abeam a reference point without overshooting its height. The reference point is located at a distance of TBD m forward of the starting point and TBD ft higher. Passing abeam the reference point, the pilot shall maneuver the helicopter to aim at a ground-referenced point located at

a distance of TBD m beyond the previous reference point. Level off will be at pilot discretion after achieving the maneuver entry airspeed.
The aim point after the pushover should not exceed ± TBD m measured horizontally from the ground-referenced point.
The maneuver is to be performed in calm wind conditions.
Positions of the reference points have to be determined in order to allow achievement of peak normal load factors at the limit of the OFE's.

Desired performance:

- *The highest point of the helicopter trajectory should pass within a window of 12 m (laterally) by 40 ft (vertically) next to the obstacle.*
- *Roll and yaw attitude angular deviations shall not exceed ±10 degrees from the initial unaccelerated flight condition until completion of the maneuver.*

Adequate performance:

- *The highest point of the helicopter trajectory should pass within a window of 18 m (laterally) by 60 ft (vertically) next to the obstacle.*
- *Roll and yaw attitude angular deviations shall not exceed ±15 degrees from the initial unaccelerated flight condition until completion of the maneuver.*

9. Cooper & Harper Ratings

Cooper & Harper ratings where assigned during all the three phases of the flight trials and ranged between 3 and 5. However, these values can not be taken into account because of different test conditions (pilot technique and aggressiveness that were not yet determined and frozen).
During a final verification phase it was intended to assess the HH-3F using the definitive test course as finally designed. However, this was only possible for one pilot due to flight time and funding availability. For this assessment ratings averaged the value of 4.
NH-90 will be required to demonstrate a CHR average of 3.5 or better.

10. Conclusions

The flight trials performed to validate the pull-up/push-over FTM started from an existing definition reported in the ADS-33C specification. Considering the NH-90 characteristics a similar class helicopter (HH-3F) was selected to be used as test bench to exploit this contour flight MTE and to modify the tolerance matrix or the test course, as required by the progression of the experimentation.
The lack of a suitable maneuver description required some initial pilot technique definition before flights.
Initial ADS-33 technique description evidently kept the pilot out of the loop requiring him to control and fly head down parameters. Therefore, decision was made to exploit the operational MTE to redefine an FTM capable to allow detection of HQ deficiencies keeping the pilot in the loop at all times and appropriately tuning aggressiveness.
This requirement was satisfied introducing adequate features in the test course so that the necessary UCE was obtained (ground referenced starting, ending points and an air referenced simulated obstacle).
The first flight results, as expected, showed a non reproducible maneuver. An empiric step-by-step approach was used to identify initial assumptions' deficiencies and to establish new ones.
One important fact was that, once the test course parameters were tuned, all other related non-piloted parameters (airspeeds, load factor values, and times at different maneuver phases) were determined as a fall-out. This paper is aimed at highlighting the need of a flexible but rigorous approach to the evaluation of the handling qualities. Lack of this set of mind could leave insidious or even dangerous deficiencies hidden, leading to important safety related issues.

11. Lessons Learned

1. An engineering theoretical approach not always grants final results, when in a handling qualities environment. This approach should always be confirmed by adequate flight test.
2. Standards in definition of performance requirements are needed to properly use the Cooper-Harper methodology. As a matter of fact, the Technical Note D5153 does not offer a precise guidance on what to look for and consider when defining a desired performance statement. This is extremely critical to appropriately assess Handling Qualities through Cooper and Harper.
3. The ADS-33 does not provide sufficient guidance on how to perform Part 3 maneuvers. A flight test manual needs to be written, following adequate testing, to cover flight test techniques for ADS-33 compliance testing. Such a text should also cover build up maneuvers and safety related issues.

4. Written specifications do not necessarily have to be blindly complied with only because “somebody has written them”. A critical approach is mandatory for a healthy test environment.
5. Appropriate training to tune pilot’s “hand” when performing tests implying approach to hardware limitations is mandatory. Engineering support is needed to predict behaviors of the test equipment.
6. Aggressiveness is a vital component to HQ flight test. Since many variables are introduced by different pilot mental attitude, technique and control strategy, particular care should be paid to create constraints that force pilot aggressiveness into a predictable envelope.

12. Acknowledgments

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ANNEX –Tables and figures

ADEQUACY FOR SELECTED TASK OR REQUIRED OPERATION *			*AIRCRAFT CHARACTERISTIC*	*DEMANDS ON THE PILOT IN SELECTED TASK OR REQUIRED ACTION*	*PILOT RATING*
			Excellent Higly desirable	Pilot compensation not a factor for desired performance	1
→		→	Good Negligible deficiencies	Pilot compensation not a factor for desired performance	2
↑			Fair- Some mildy unpleasant deficiencies	Minimal pilot compensation required for desired performance	3
↑					
Is satisfactory without improvement ?	No →	Deficiencies warrant improvement →	Minor but annoying deficiencies	Desired peformance requires moderate pilot compensation	4
			Moderately objectionable deficiencies	Adequate performance requires considerable pilot compensation	5
			Very objectionable but tolerable deficiencies	Adequate performance requires exstensive pilot compensation	6
↑					
Is adequate performance attainable with a tolerable pilot workload?	No →	Deficiencies require improvement →	Major deficiencies	Adequate performance not attainable with maximum tolerable pilot compensation	7
			Major deficiencies	Considerable pilot compensation is required for control	8
			Major deficiencies	Intense pilot compensation is required to retain control	9
↑					
Is it controlable?	No →	Improvement mandatory →	Major deficiencies	Control will be lost during some portion of required operation	10
↑					
Pilot decision					

Cooper- Harper Ref. NASA TND-5153

* Definition of required operation involves designation of flight phase and/or subphases with accompanyng conditions

Table 1 : Cooper & Harper handling qualities rating scale

Helicopters	Lenght (m)	Blade number	Blade Lenght (m)	T/O Weight (Kg)	Nominal rotor speed (Rpm)	Ct $\frac{W_{T/O}}{\rho S(\omega r)2}$	Vtip =ωR (m/s)	Hinge offset (m)	Focal distance (m) (1)
HH 3F	19.05	206,76	9,45 (5 blad.)	9100	209	0.000834	213.7	0.33	2.04
NH 90	16.108	218,42	8,15 (4 blad.)	10002	256	0.000914	226.5	0.3	2.34

(1): The "Focal distance is related to the helicopter pitch control moment"

Table 2. Comparison between some HH3F and NH90 helicopters characteristics.

Helicopters	Mission Conditions	Pressure Altitude (m)	OAT (°C)	Weight (Kg)	Ct NH- 90 $\frac{W}{\rho S(\Omega r)^2}$	Ct HH-3F $\frac{W}{\rho S(\Omega r)^2}$
NH90 TTH	WSDS	1000	23.5	8700	0.000836	0.000693
NH90 NFH	WSDS	0	25	9100	0.000775	0.000643
HH3F	Flight Test	0	15	8182	0.000672	0.000558

Table 3. Comparison between disk loading amongst HH-3F at test conditions and both versions of NH-90 at respective mission reference conditions.

	ENTRY POINT		Pull - up		TOP POINT				EXIT POINT			Δ Time	
Nr	Z_{Entry} (ft)	V_{Entry} (KIAS)	Nz	Pitch (°)	Z_{target} (ft)	ΔY_{HH3F} ΔZ_{HH3F}	V_{Top} (KIAS)	Nz_{Top}	Z (ft)	Pitch (°)	V_{Exit} (KIAS)	Entry-Top. (s)	Top-Exit (s)
1	500	130	1.5	13	600	ΔY 50 ft Before ΔZ OK	115	0.5	300	21	140	4	15
2	500	125	1.5	19	600	ΔY 50 ft Bef. ΔZ 50 ft up	100	0.5	450	22	125	4	10
3	450	132	1.6	20	600	ΔY Central ΔZ 30 ft up	100	0.6	350	21	130	5	11
4	450	130	1.6	20	600	ΔY Central ΔZ OK	100	0.5	400	20	130	6	10
5	450	134	1.6	20	600	ΔY 50ft Before ΔZ 70 ft up	110	0.5	300	20	130	5	9
6	500	130	1.5	20	600	ΔY Central ΔZ OK	100	0.5	400	20	130	5	11
7	500	130	1.5	20	600	ΔY Central ΔZ 70 ft up	100	0.5	400	20	130	4	12
8	480	130	1.5	20	600	ΔZ 100 ft up ΔY 70 ft after	90	0.6	500	20	125	7	9
9	500	130	1.6	20	600	ΔY 30 ft Before. ΔZ 120 ft up	100	0.5	500	20	125	5	9
10	500	137	1.5	20	600	ΔZ 30 ft up ΔY 20 ft after	107	0.4	450	20	130	5	10

Table 4: HH-3F Phase 3 trials test results

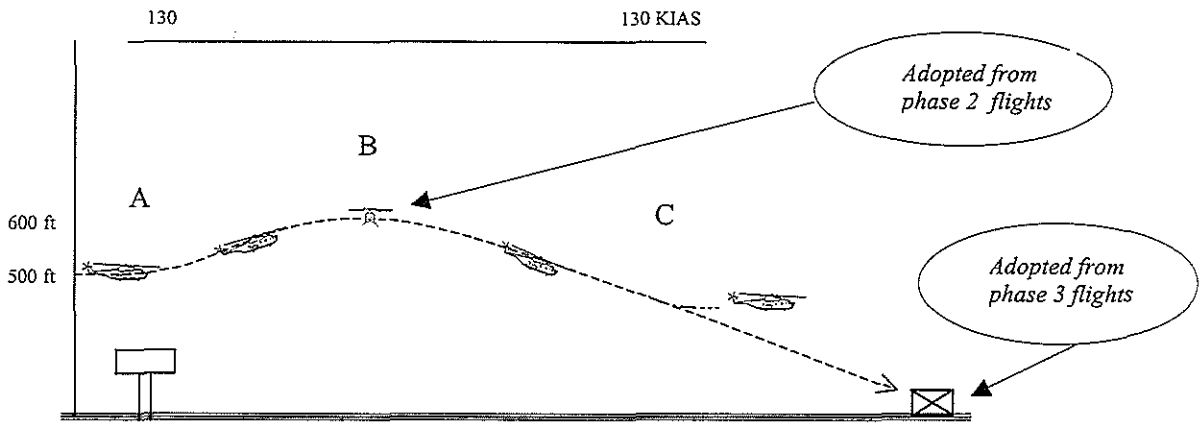

Figure 5: SUGGESTED TEST COURSE FOR HH3F TRIALS
A: Entry Point B: Top Point C : Exit Point

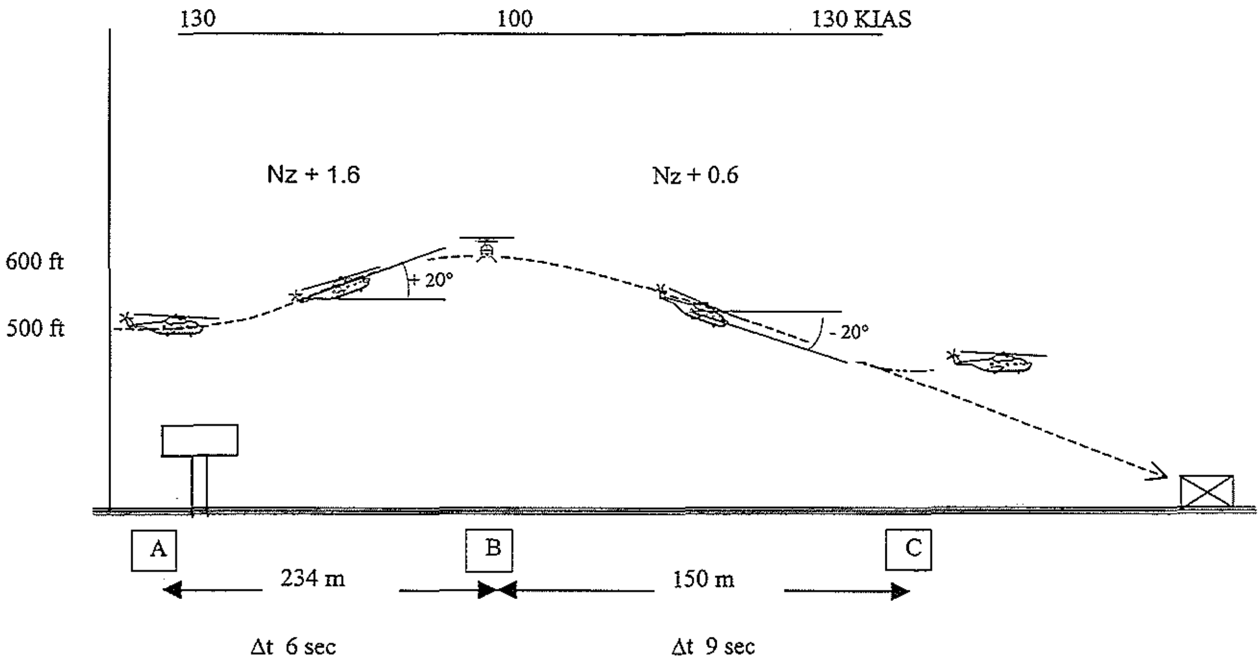

Figure 6: ACHIEVED RESULTS FOR HH-3F Pull up - Push Over flight trials