Annex B – IN-FLIGHT STUDIES WITH TACTILE DISPLAYS

B.1 FLIGHT TESTS USING TSAS

The US Navy developed a Tactile Situation Awareness System (TSAS) consisting of a vest with a 3-D matrix of tactors, providing the pilot with attitude information of the aircraft [1];[2].

Under a formal ASIC (Air and Space Interoperability Council, formerly ASCC) Test Project Agreement (TPA) an in-flight study was conducted in Uplands airfield, Ottawa, Ontario between July-August 2003, to evaluate the effect of TSAS in maintaining high hover and in simulated ship-borne landing in a Bell 205 helicopter. The collaborative study is a joint effort between DRDC Toronto, the Naval Aerospace Medical Research Laboratory (NAMRL) of the US Navy, and the Flight Research Laboratory (FRL) of the National Research Council (NRC) of Canada. The methodology and significant findings are summarised below.

It has been proposed that providing position information to pilots with TSAS may significantly improve performance in situations where precise hovering over a spot is required, i.e., search and rescue, troop insertion. A series of studies was conducted to investigate the usefulness of the TSAS in maintaining High Hover (HH, 150 feet above ground) and a simulated ship-borne landing – Maritime Hover (MH). Eleven experienced pilots from Canada and the United States participated in the study. The pilots' background experience includes tactical, search and rescue, special operations and test pilots. The TSAS flight prototype employed a 24 pneumatic tactor array (8 columns and 3 rows around the torso) and 4 electromagnetic tactors (2 on the shoulder and 2 on the ventral thigh area). The system receives data from current aircraft systems, and relays horizontal position data via the pneumatic tactors and vertical position data via the electro-magnetic shoulder and thigh tactors. Night vision goggles fitted with a light filter were used to create a Degraded Visual Environment (DVE) as compared to Good Visual Environment (GVE) without night vision goggles. Longitudinal, lateral and vertical deviations from the designated position with and without TSAS were measured. The China Lake Situational Awareness scale and the Modified Cooper Harper Workload Rating scale were solicited in-flight. Subjective performance self-evaluation, workload assessment (Subjective Word Dominance), and perceptual cueing responses (modified from visual cue rating) were solicited from the subject post flight. From the high hover trials, flight performance data suggested that in a degraded visual environment, TSAS lessened horizontal and height deviations. Analysis of subjective responses revealed that TSAS appears to significantly improve Situation Awareness (SA) but did not significantly decrease workload in both manoeuvres. Subjective performance and perceptual cueing indicated general improvement with TSAS.

During simulated ship-borne landing trials, the task required the pilot to track a vertically moving target that simulates ship-borne movements, in two separate sea states; Sea State 3 (SS3) and Sea State 5 (SS5). Once established in a stable hover, the pilots tracked a moving target in the vertical direction by adjusting the height of the aircraft, while attempting to maintain the same position over the ground. TSAS provided horizontal displacement information via the tactors. Displacements in the horizontal plane from the original hover position, and subjective measures of SA and workload were recorded in-flight. Post-flight measures included workload assessment, perceptual cue ratings and subjective self-assessment. Our data indicated that TSAS was effective in reducing the average longitudinal and lateral deviations in GVE and DVE during sea states 3 and 5. Our results also revealed that TSAS improved situation awareness in DVE, with a significant result recorded for SS5 (p = 0.012). Perceptual Cue Rating scale results revealed that in SS5 and DVE, the horizontal translational rate cue was rated significantly better with TSAS (p = 0.025). Workload assessment ratings showed that TSAS appeared to play a role in decreasing workload. We conclude that TSAS

is an effective tool for improving pilot performance and SA and has the potential to increase safety during maritime helicopter operations. The increase in performance due to TSAS appeared to be especially beneficial during poor visual conditions and high sea states without the penalty of increased workload. Subjective self-evaluation by the pilots showed a correlation to actual performance, indicating improved confidence in their ability to perform the task. Details of this study has been reported by [3].

B.2 TSAS LITE

Recently, Curry, Estrada, Webb and Erickson (2008) [4] demonstrated the efficacy of tactile stimulation as a drift cue in a flight environment. Rather than the full TSAS version, consisting of an extensive vest of tactors, a belt consisting of 8 electromagnetic tactors placed every 45 degrees was evaluated by U.S. Army UH-60 rated pilots in a UH-60A aircraft. The prototype Tactile Situation Awareness System; TSAS-Lite tactile display system uses the sense of touch to provide drift to aircraft operators. The TSAS-Lite system accepted data from the aircraft via the ASN-128D-Doppler Global Navigation System to obtain the aircraft position, velocity, and vector. Drift information was then displayed via the electromagnetic tactors located on the belt (Figure B-1).

Figure B-1: TSAS-Lite Belt.

The system consisted of a Commercial-Off-The-Shelf (COTS) PC-104 Central Processing Unit (CPU) (Real-Time Devices CMC6686GX233HR-128), a custom 8-channel tactor driver board and eight electromechanical tactors (Engineering Acoustics, Inc.). The tactors provided a vibrating stimulus at 90 Hertz (Hz) +/- 20% with three rates of firing depending on pre-set ground speeds (0 – 15 knots (kts): 200 ms, 15 – 30 kts: 600 ms, 30 – 45 kts:1000 ms). The sensation was similar in intensity to a standard electric toothbrush. The prototype belt was made of flexible neoprene with Velcro fastenings and was worn sufficiently tight around the belt area to provide tactor contact while still being comfortable. The CPU and tactor drive electronics were housed in a water resistant sealed housing, with data, tactor and operator switch interfaces. For operational use, the system could interface to existing military GPS units or COTS sensors. The system required only digital data from position or direction sensors.

The pilots received an hour training flight in a simulator to demonstrate the use of the tactile belt. The experimental flights consisted of landings, take-off and hover maneuvers while utilizing frosted goggles to limit the pilots' vision to the instrument panel. During take-off, hover flight, and approach to landing,

location of the tactor on belt-line was used to indicate direction of helicopter motion, and tactor activation pulse pattern was used to indicate the velocity of helicopter drift. The belt was tested in rested and sleep-deprived conditions. The objective flight performance data revealed significantly less drift errors during the hover while wearing the tactile belt. Figure B-2 contains an example of hover performance with and without the TSAS-Lite belt. In addition, pilots reported the TSAS-Lite belt significantly improved their perception of drift, increased their SA, and reduced their mental stress. The study demonstrated that a limited tactile display can provide increased mission effectiveness and safety in the critical areas of low speed maneuver near the ground in degraded visual conditions.

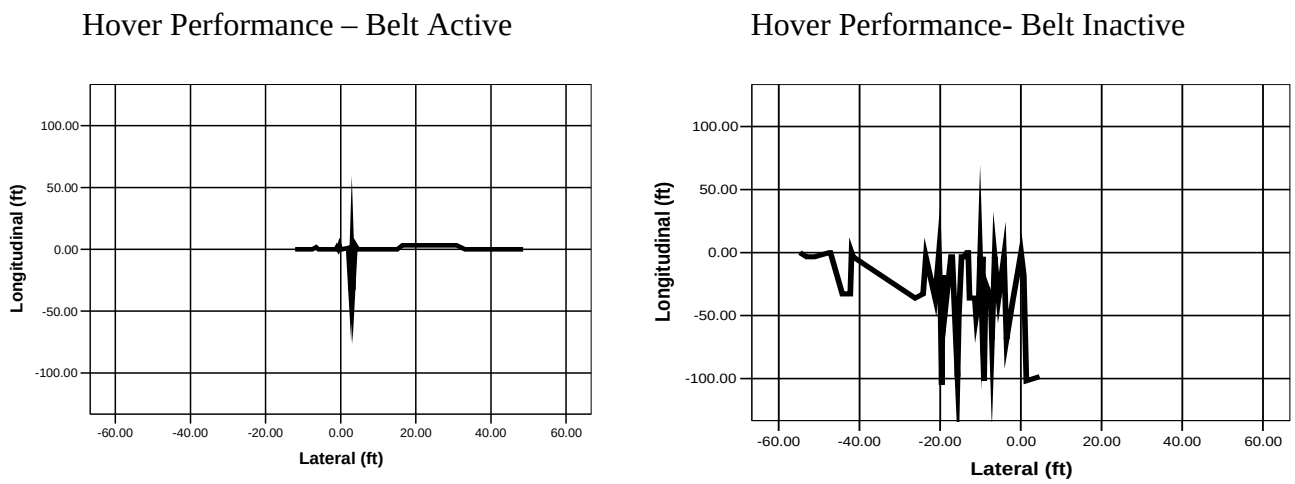

Figure B-2: Ground Track During Hover Performance. Note: These graphs illustrate the performance of the same participant under sleep-deprived conditions [4].

B.3 FLIGHT TEST WITH TNO TACTILE TORSO DISPLAY

The Dutch research organization TNO built up extensive experience with a tactile torso display consisting of a vest with 64 tactors, arranged in 12 columns and five horizontal rings. The tactors used so far are custom-built, based on DC pager motors (i.e., a rotating eccentric mass) which are housed in a PVC block with a contact area of 1.5 by 2.0 cm. Typically, these tactors vibrate at 150 Hz.

TNO performed various studies in flight simulators as well as in an actual helicopter showing that pilots effectively use tactile feedback for control tasks (altitude, hover), navigation tasks (waypoint navigation), and recovery from spatial disorientation [5];[6];[7].

In a recent flight test with a Eurocopter AS 532U2 Cougar MkII an adapted version of the TNO tactile torso display (Figure B-3 and Figure B-4) was evaluated in supporting helicopter pilots during Brownout landings [8]. Based on a series of simulator trials with RNLAF rated test pilots *ground speed* and *height-above-terrain* were identified as the essential flight parameters for the operational procedure used in Brownout landings. The configuration of the tactile torso display was modified so as to present these flight parameters with higher spatial resolution. The direction of horizontal helicopter motion (i.e., the direction of the groundspeed vector) was presented on a horizontal array of 31 tactors, covering the frontal 180 deg. This yielded inter-tactor intervals of 6 deg. Tactors were activated in 200 ms on / 200 ms off-bursts. In one experimental condition the magnitude of groundspeed (i.e., the length of the ground speed vector) was indicated by increasing the on/off

rhythm proportionally to groundspeed. Height-above-terrain was indicated on a vertical strip of 21 tactors on the pilot's back. The lowest tactor indicated ground level by a continuous 200 ms on/off pattern. The actual altitude was presented by one of the other tactors, activated in anti-phase with the ground reference tactor. This caused the sensation during the descent that a vibration was 'walking' down on the back towards to lowest tactor representing ground level. If altitude was below 5 ft, current altitude and ground level were presented by the same tactor, resulting in a continuous activation of the lower tactor. The other inter-tactor intervals were 7 ft.

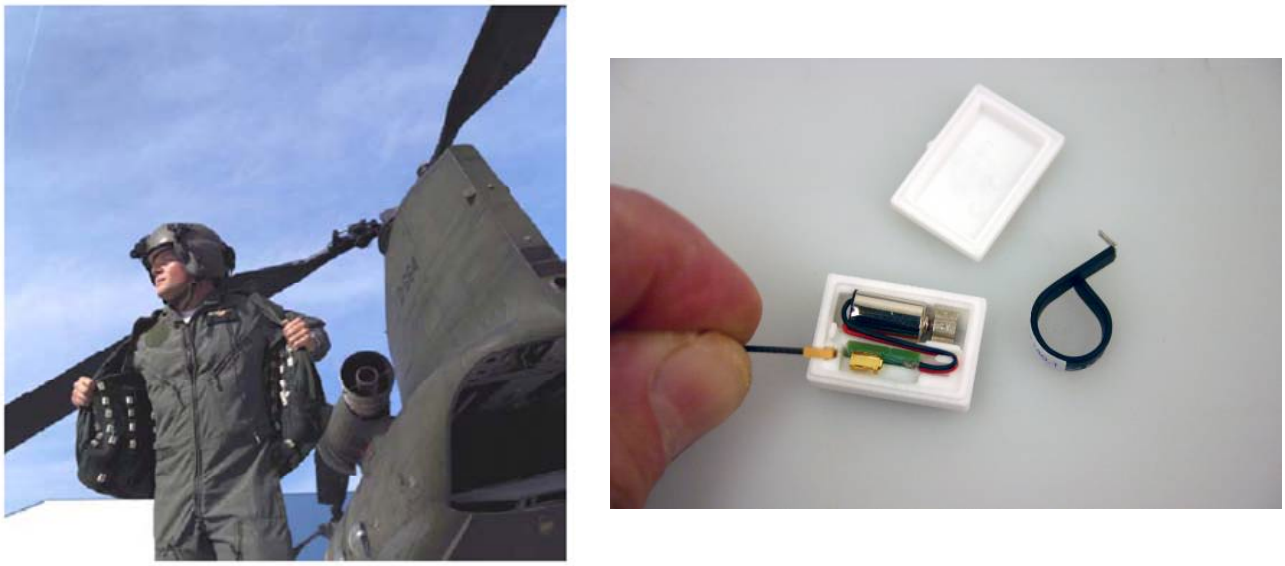

Figure B-3: TNO Tactile Torso Display (Left) and Inside View of a Tactor (Right).

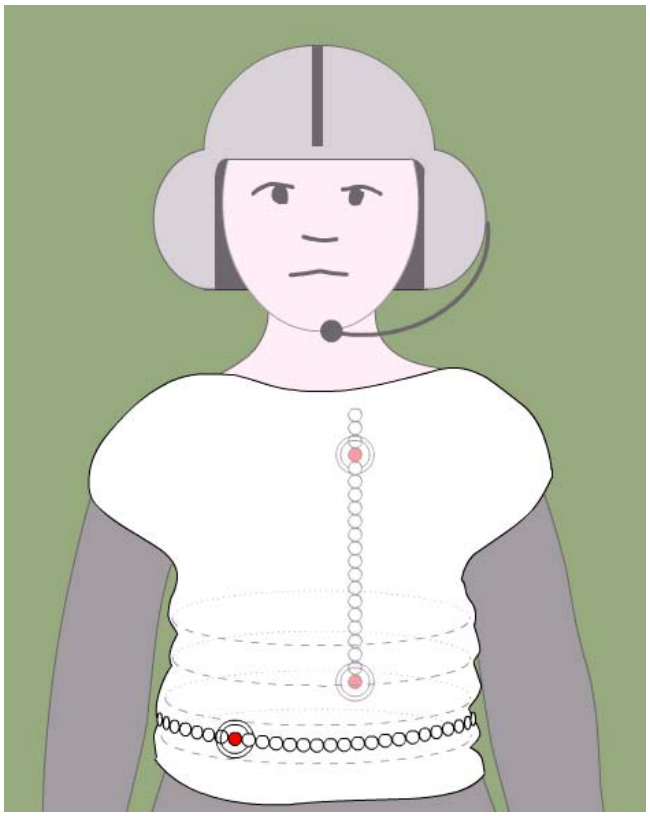

Figure B-4: Cartoon Showing the Horizontal Tactor Array for Indication of Groundspeed, and the Vertical Array for Indication of Height-Above-Terrain.

It is interesting to note that the tactors were placed about 1 cm apart from each other. This is below the spatial discrimination threshold of about 3 – 4 cm which is found for most parts of the human torso [9]. However, this spatial acuity has been determined using non-moving tactile signals, whereas the tactile signal indicating ground speed is dynamically moving along the tactor array in response to control inputs of the pilot. During the simulator trials it was found that a moving tactile signal resulted in a sensation of "apparent motion" even with a higher density of tactors. Hence, the spatio-temporal resolution is higher than pure spatial resolution, which allows for placing more tactors at shorter distances.

In the flight test height-above-terrain (radio altitude meter) and groundspeed (Doppler radar) were acquired via the Cougar's data bus. The starting point of the test manoeuvre was at 70 ft, with a groundspeed of 0 kts. It would speed up to about 25 – 30 kts during the descent. The helicopter "landed" at an altitude of about 10 ft next to the reference object (a 500 W lamp). The start location had a lateral offset of 130 ft with respect to the landing position, with the objective to introduce side drift that had to be dealt with during the landing maneuver. Each maneuver took 22 to 45 seconds.

Brownout-like impaired vision conditions (Degraded Visual Environment, DVE) were simulated using coloured sheets on the left half of canopy (Lee filter LHT116 HT Medium Blue Green) and test pilot's visor (Lee filter L164 Flame Red, double layer with both standard visors down). This way, the test pilot could see the cockpit instruments (looking through only the red filter) but little more of the outside scenery than a 500 W lamp on the ground (looking through both red and blue/green filters), and vaguely the horizon.

The safety pilot's view was only slightly restricted by the blue/green filter on the left half of the canopy. In control conditions in Good Visual Environment (GVE) condition, the pilot put up his visor, thereby having the same clear view as the safety pilot on the outside scenery.

All trials were performed by a Cougar test pilot. In total we tested seven conditions: GVE without tactile information; DVE without tactile information, and DVE with five different combinations of tactile information (bearing, height-above-terrain, bearing plus height-above-terrain, bearing plus speed, bearing plus speed plus height-above-terrain). Each condition was tested three times, and the total test flight lasted about 90 minutes. The recorded flight parameters showed that in the GVE condition, the maneuver was performed in about 23 s with an average groundspeed of 17 kts. Angular deviation averaged over the entire run amounted to one deg. In the DVE condition without tactile support average speed amounted to 11 kts, resulting in a mean duration of 36 s. Angular deviation was 13 deg. In all five DVE conditions *with* tactile support, performance improved compared to the DVE without tactile support: average speed varied closely around 14 kts, so that the maneuver was performed in substantially shorter time. Angular deviation remained below 3 deg. See references showing time histories of height-above terrain, forward and lateral speed for three conditions; Bearing and Altitude (i.e., tactile information on direction and height), Clear Vision (i.e., GVE), and no tactile support (i.e., DVE). See Figure B-5.

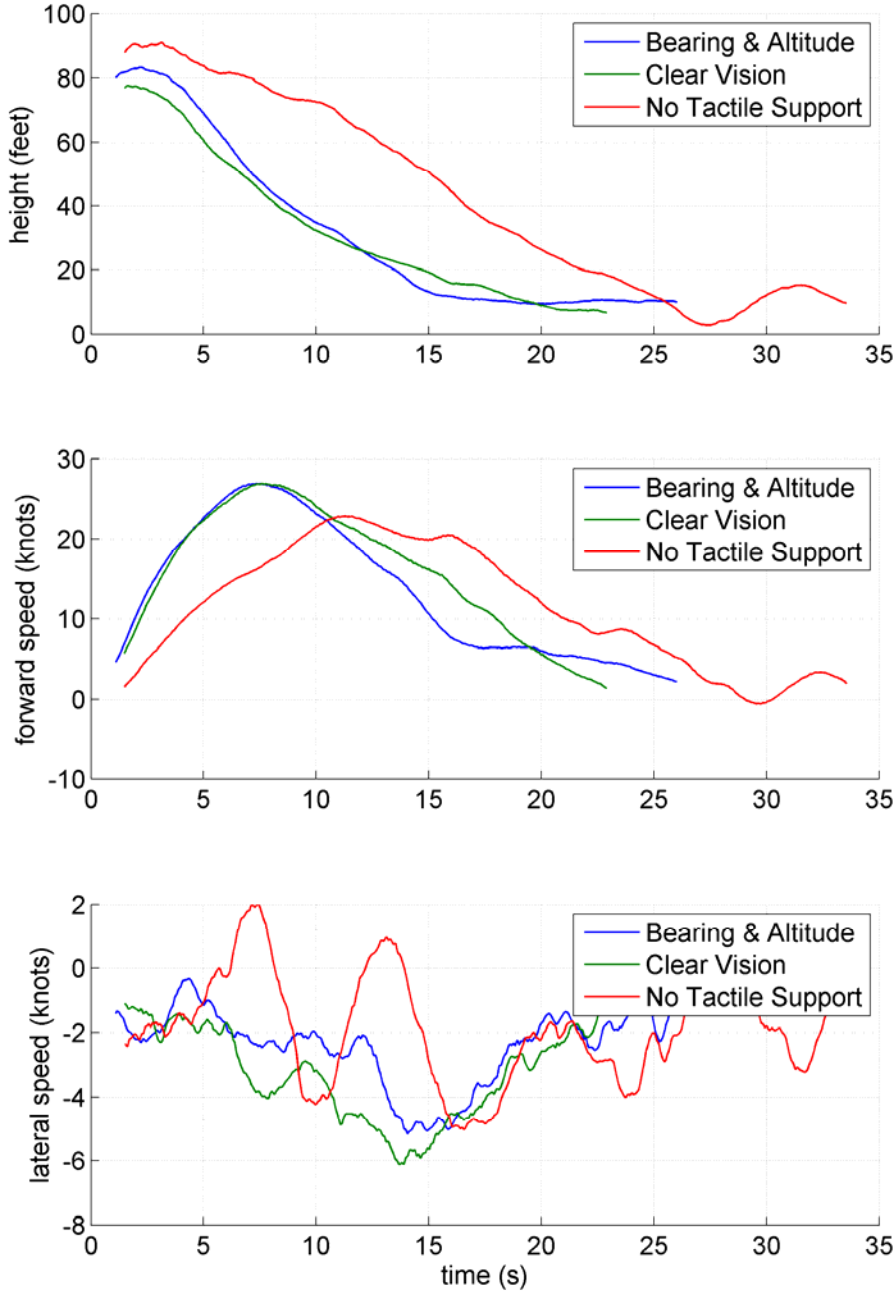

Figure B-5: Recorded Height-Above Terrain (Upper Plot), Forward Speed (Middle), and Lateral Speed (Bottom) Recorded During the Last Landing Maneuver in Three Conditions (Bearing and Altitude Information Presented on Tactile Display, Clear Vision, and No Tactile Support).

The pilot commented afterwards that the tactile information on height-above-terrain and bearing was very useful. This was reflected in the Handling Qualities Rating (HQR) data (Figure B-6. In the GVE condition the HQR was 3, indicating that the pilot could achieve the desired performance. In the DVE trials without tactile support the HQR was 7 on average (inadequate performance, pilot compensation needed), whereas in the

DVE trials with tactile support the HQR amounted to 5 which means that adequate performance levels were met, although requiring some pilot effort. According to the pilot, the tactile coding of the magnitude of the groundspeed vector (i.e., where tactile rhythm was proportional to speed) required too much mental effort to interpret. Indication of the direction of helicopter drift was already sufficient.

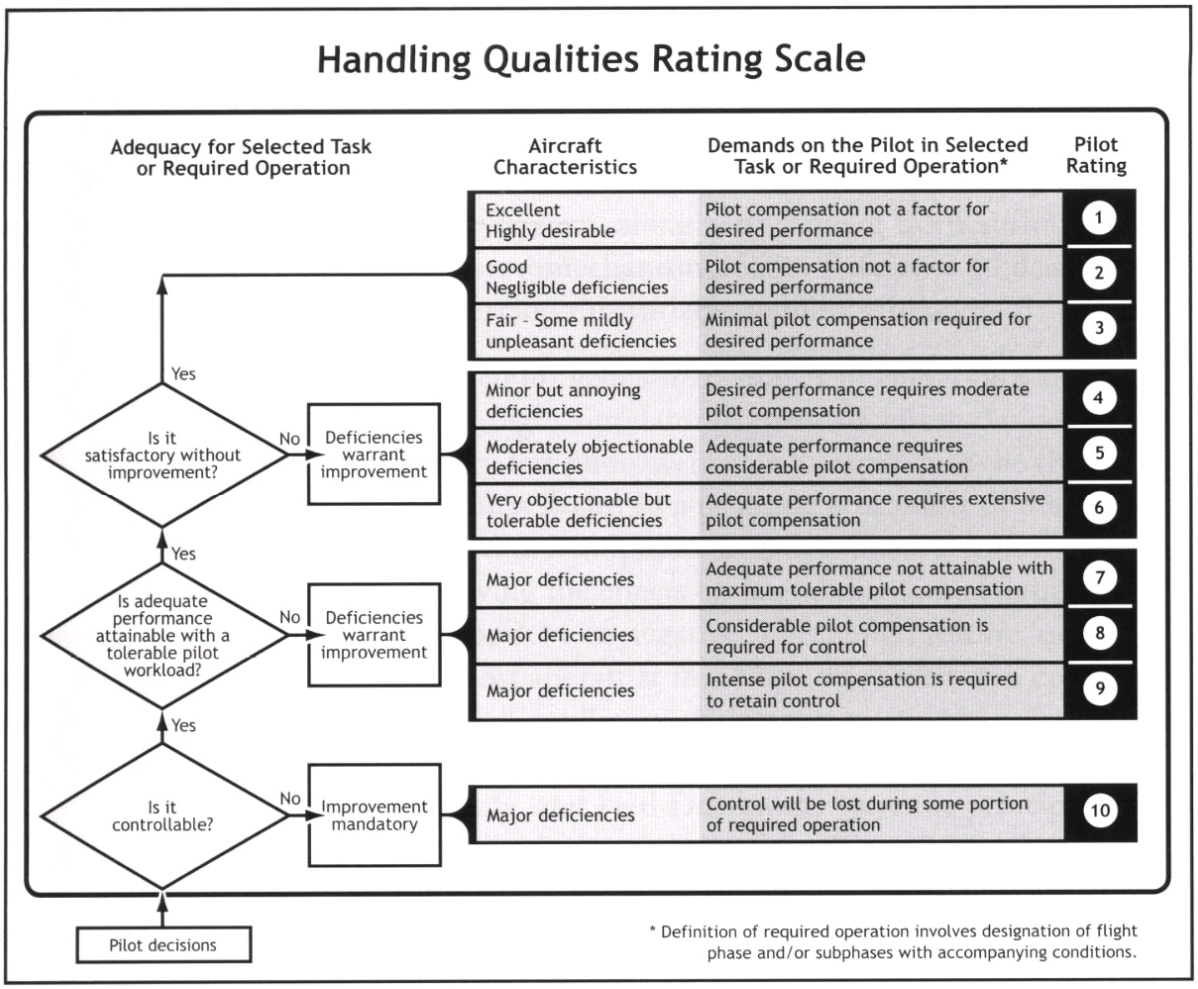

Figure B-6: Handling Qualities Rating Scale.

B.4 CONCLUDING REMARKS

The described flight tests show that tactile displays support manoeuvring helicopter DVE landings. The improved performance (less drift, higher landing speeds) show that tactile information increases mission effectiveness. In particular the finding that with tactile support the landing manoeuvre was performed at higher speed, and thus in less time, implies that the pilot has better chance to stay ahead of the dust cloud.

Interestingly, the studies performed by USAARL and TNO used different tactile configurations, showing that the design of the tactile display depends on the airframe, flight task, and landing procedure.

B.4.1 Open Issues

Despite the promising results of these studies, it should be noted that the tactile technology has not yet been certified for operational use. The tactile displays used should be considered prototypes. Additional research is needed to determine the optimal configuration for a certain landing procedure. Several other questions, both concerning hardware and the use, should also be answered before applying tactile technology in a cockpit. The most important questions concern:

- How well do pilots perceive tactile cues under heat stress?
- Perception under helicopter vibrations (whole body vibration).
- Will tactile cues still be addressed to while under severe workload or stress? It is known that auditory cues may be neglected under stressful conditions. We do not know yet whether this may also be the case with tactile cues.
- How to connect the tactile display to the helicopter power supply and data bus? Or should the tactile display be self-supporting?
- How can we integrate tactors in (existing) flight suit or in pilot seat?
- The integration of information regarding tactile display with other dust penetrating technologies requires investigation.

B.5 REFERENCES

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