OBJECTIVE AND SUBJECTIVE ESTIMATION OF THE *SOKOL* HELICOPTER PERFORMANCES ON THE BASIS OF TEST FLIGHTS

Grzegorz Kowaleczko
Military University of Technology
ul. Kaliskiego 2, 00-908 Warsaw, Poland
E-mail: kowaleczko@wul.wat.waw.pl

Jerzy Berezanski and Kazimierz Szumanski
Institute of Aviation
Al. Krakowska 2, 02-256 Warsaw, Poland
E-mail: kszu@il.ilot.edu.pl

Abstract

The paper presents exemplary results of handling qualities and flight performances evaluation of a helicopter. They were obtained during test flights, which were performed with the Polish *Sokol* helicopter. Two methods of evaluation were applied. The first one utilised the Cooper-Harper rating scale. The second one was based on ADS 33 norm. These methods allowed subjective and objective evaluation of this helicopter. Some results were compare with handling qualities and flight performances of other helicopters.

1. Introduction

Cooper and Harper have defined *flying qualities* as "those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the task required in support of an aircraft role . According to [3] flying qualities can be divided into two categories. The first one describes helicopter behaviour in response to pilot controls. The second kind of them characterises helicopter replay to external disturbances.

Two methods of evaluation of the handling qualities and flight performances are applied. The first one applied **the Cooper-Harper rating scale**. This is the subjective method of evaluation based on pilots' opinions about a helicopter and its behavior during flights. For years it has been the main method of evaluation. Because rating of each pilot is subjective, special procedures of evaluation should be used. The Cooper-Harper rating scale has a decision tree structure. A set of question/answer sequences allows determining a final rate /Fig.1/. Sometimes a cooperation between a pilot and a test engineer is desired to obtain this rate. Each manoeuvre is evaluated separately. A programme of test flights should be worked out very studiously. These flights should be performed for the same helicopter configuration and the same environmental conditions. Owing to this the same aircraft characteristics are evaluated and the influence of other factors can be neglectible. One should underline that all these evaluations are still subjective.

On the basis of the obtained rates each helicopter can be classified at one of three levels. At *Level 1* /rates 1÷3/ its flight performances are excellent and it can be used in every mission in the operational flight envelope /OFE/. If the helicopter is located at *Level 2* /rates 4÷6/, it means that its handling qualities are still good and task performances are adequate but some compensations, from moderate to extensive one, are necessary to perform the mission. The external rate of *Level 2* /6/ signifies that the mission is still flyable but only for a short time and the pilot is not able to execute any other tasks. In the case of *Level 3* /rates 7÷9/ the flight qualities of the helicopter are not acceptable and the aircraft should not be utilised. The rate 10 means that the aircraft is uncontrollable and any task is not impracticable.

The above remarks are based mainly on [1]÷[3], where the exact description of the whole evaluation procedure can be found.

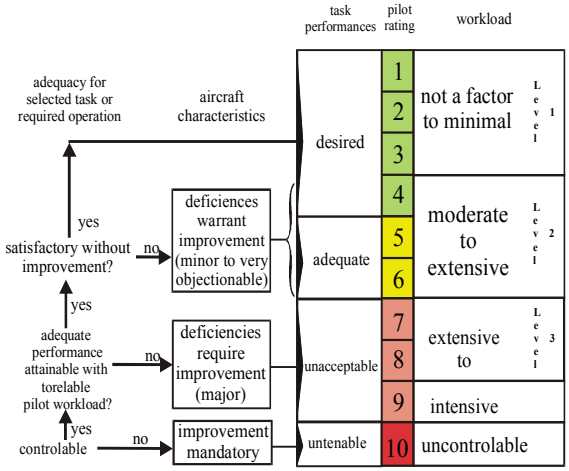

Fig.1. The Cooper-Harper handling qualities rating (HQR) scale – summarized form /Rf.[3]/

The second method of handling qualities and flight performances evaluations is based on **the ADS 33 norm** /*Aeronautical Design Standard – Handling Qualities Requirements for Military Rotorcraft*/, which is the main source of objective criteria for estimation of helicopter flight characteristics. These criteria are defined for a set of individual manoeuvres and they compose the basis of the helicopter evaluation during its design and certification phases

In this norm each operational flying tasks are divided into a series of elementary missions, which are named Mission Task Elements /MTE/. All MTE are the same for different helicopters executing various flying tasks. Each MTE is precisely defined by a set of various kinematic parameters. They are complemented with additional conditions, which describes circumstances of MTE. This allows taking into account the full operating context, which come from a peculiarity of flying tasks. This is particularly important for military helicopters performing nap-of-the-earth missions or for civil helicopters executing extremely difficult tasks, for instance the offshore supply mission. The ADS norm also takes into account the weather, temperature and visibility. Normal and failed states, full and divided pilot attention are also included into considerations. Thanks to this, the outer factors are the same or similar and they don't influence rates of the tested helicopter. Rates of various helicopters can be compared. What is more, the rates are also based on objective evaluation of the helicopter behaviour. Some kinematic parameters are recorded during test flights and on the basis of them various types of helicopter response are analysed. The frequency and amplitude characteristics are fundamental in these investigations. They allow classifying the helicopter into one of *Levels*. These levels are similar to those from Fig.1. The ADS 33 supplies quantitative norms of responsiveness and sensitivity for each MTE as well as mandatory quality boundaries laid down on measurable parameters.

2. Test flights

Handling qualities were determined for the Polish *Sokol* helicopter. A programme of test flights was worked out. Determination of an extreme operational flight envelope and its handling qualities was the main goal of these investigations. Test flights were performed in 1999 at a helicopter factory airfield in Swidnik. All flights were executed in agreement with the ADS-33 norm. Investigations consisted of two stages. At the first stage the preliminary assessment of manoeuvrability was done. After these tests, on the basis of the analysis of the obtained results, the necessary modifications of pilotage techniques were brought in. Next the final assessment was performed.

A programme of tests contained the following nap-of-the-earth manoeuvres:

- precision manoeuvres:
  1. Hovering Turn
  2. Pirouette
- aggressive manoeuvres:
  3. Turn to Target
  4. Bob up to Hover
  5. Acceleration and Deceleration
  6. Sidestep
  7. Slalom
  8. Deceleration to Dash
  9. Transient Turn
  10. Pullup/Pushover
  11. High Yo-Yo
  12. Low Yo-Yo

Each flight was analysed and handling qualities of the helicopter were evaluated and reported by pilots – subjective autonomous assessments of each manoeuvre were done. The Cooper-Harper scale was applied.

During test flights a great deal of parameters were recorded. On the basis of the data acquired it was possible to perform an objective evaluation of the helicopter. This kind of assessments was based on the ADS norm. The main goal of these investigations was to answer the following questions:

- Does the *Sokol* helicopter satisfy the ADS norm and at which level?
- What should be changed in a pilotage technique to satisfy the ADS norm at least at *Level 2*?
- How wide is a control margin for each manoeuvre?

3. Results

3.1. Subiective assesment

Fig.2 presents the final rates of the *Sokol* helicopter obtained on the basis of the Cooper-Harper rating scale. Because of various limits only two pilots took part in investigations. Therefore, one of formulated in [3] rules was not fulfilled. One can see that all rates are at least at *Level 2* or even *1*. It means, that the manoeuvrability of the *Sokol* helicopter is comparable with manoeuvrability of other equivalent helicopters. Fig.3 shows exemplary comparison with the Appache AH-64 and the Black Hawk UH-60A /Ref.[3]/.

Manoeuvre	Assessments		
	Berezanski	Jaworski	Average rate
Precision manoeuvres			
Hovering Turn	4	3	**3.5**
Pirouette	4	4	**4**
Aggressive manoeuvres			
Turn to Target	3	3	**3**

Bob up to Hover	4	4	**4**
Acceleration and Deceleration	4	4	**4**
Sidestep	3	3	**3**
Slalom	3	3	**3**
Deceleration to Dash	4	4	**4**
Transient Turn	4.5	3.5	**4**
Pullup/Pushover	4.5	4	**4.25**
High Yo-Yo	3.5	3.5	**3.5**
Low Yo-Yo	3.5	3.5	**3.5**

Fig.2 Handling qualities assessment of *Sokol* helicopter /Cooper-Harper rating scale/

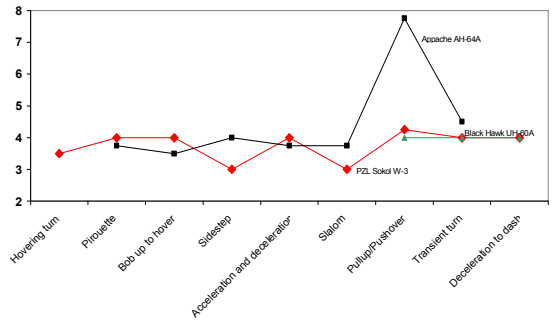

Fig.3 HQRs for various helicopters flying ADS-33 tasks

3.1. Objective assessment

This part of the paper presents some selected results of the *Sokol* manoeuvrability analysis on the basis of ADS-33 norm. The nap-of-the-earth manoeuvres were executed.

Slalom

Slalom is a typical combat manoeuvre, which is utilised for a horizontal bypassing of obstacles. It is performed close to the earth. As a result of this, the helicopter is invisible for enemy radars.

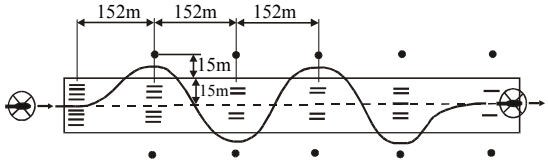

Fig.4 Suggested course for *Slalom* manoeuvre /Rf.[2]/

This manoeuvre should be initiated by a horizontal steady state flight at an altitude below 30.5 m /100 ft/. A series of turns at 152 m /500 ft/ intervals should be performed with the maximum lateral error of 15.2 m /50 ft/ from the centreline /Fig.4/. The main task is to maintain an airspeed of at least 75 km/h /40 kts/ - desired performance or 111km/h /60 kts/ - adequate performance. Fig.5 shows results obtained during test flights.

One can observe that requirements of the *Level 2* were fulfilled. Taking into account the fact that this manoeuvre was performed with a limited aggressiveness, one can realise that the *Level 2* can be easily reached. During the *Slalom* manoeuvre only 20÷40% of lateral control range was used.

Criterion	ADS 33 requirements		Results
	Desired	Adequate	
Minimal airspeed	111 km/h	75 km/h	115 km/h
Maximal altitude	30 m	30 m	25 m

Fig.5 Results of the *Slalom* manoeuvre

This manoeuvre was performed with surprisingly ease and moderate aggressiveness. It means that the slalom can be performed at higher airspeed and the ADS-33 norm is fulfilled with a large margin.

On the basis of the recorded parameters a control effectiveness parameter was determined. In this case it was defined as follows:

$$\frac{p_{pk}}{\Delta\Phi_{pk}} = f\left(\Delta\Phi_{\min}\right)$$

and could be named *roll attitude quickness*. p_{pk} was the peak angular rolling velocity and $\Delta\Phi_{pk}$ was the peak roll angle change during a discrete manoeuvre. Fig.6 presents the obtained coefficient versus the minimum roll change $\Delta\Phi_{\min}$.

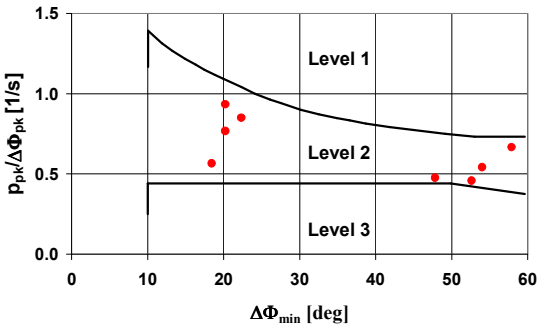

Fig.6 Roll attitude quickness points

Sidestep

Sidestep is a typical helicopter manoeuvre. At the battlefield it is utilised to fire from behind a terrain screen. The helicopter is hidden by the screen all time and leans out only for a short time necessary for the effective aiming and shooting. Sidestep should be executed very quickly but also very finely.

This manoeuvre should be started from a stabilised hover with the longitudinal axis of the helicopter oriented 90 degrees to a reference line marked on the ground /Fig.7/. A rapid and aggressive lateral translation should be initiated with the bank angle of at least 25 degrees. An altitude should be constant. An aggressive deceleration to hover at constant altitude should be

immediately initiated, when a lateral velocity approaches within the 9.25 km/h range its maximum lateral airspeed, or reaches 83.25 km/h, whichever is less. A stabilised hover should be maintained for 5 seconds. Next the same manoeuvre is executed in the opposite direction. The peak bank angle during deceleration should be at least 30 degrees. A wind may be calm or headwind less than 18.5 km/h. Fig.8 shows results obtained during the *Sidestep* in the performed tests.

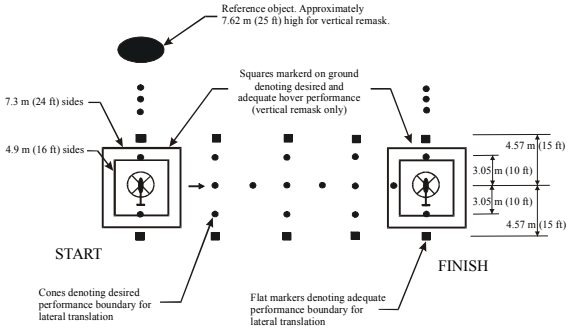

Fig.7 Suggested course for *Sidestep* manoeuvre /Rf.[2]/

Criterion	ADS 33 requirements		Results
	Desired	Adequate	
Minimal bank angle during acceleration	25^0 within 1.5 sec of initiating acceleration	25^0 within 3 sec of initiating acceleration	$\geq 25^0$
Minimal bank angle during deceleration	30^0 within 1.5 sec of initiating deceleration	30^0 within 3 sec of initiating deceleration	$\geq 30^0$
Maintenance of altitude	±3.05m at a selected altitude below 9.14m	±4.57m at a selected altitude below 9.14m	≤±3.05m
Maintenance of heading	$\pm 10^0$	$\pm 15^0$	$\leq \pm 10^0$
Maintenance of longitudinal orientation	±3.05m	±4.57m	≤±3m
Time of hover stabilising after its achieving	≤5 sec	≤10 sec	≤5 sec

Fig.8 Results of the *Sidestep* manoeuvre

On the basis of these results one can see that the *Sokol* fulfilled all desired ADS-33 requirements. This is confirmed by Fig.9. This figure presents roll attitude quickness points for the *Sidestep*. Results of the *Sokol* are compared with the Lynx /Ref.3/. Taking into account the fact that during test flights no full use of *Sokol* maneuverability features were made, it can be supposed that this manoeuvre can be performed more aggressively. A margin of lateral control was more than 40%.

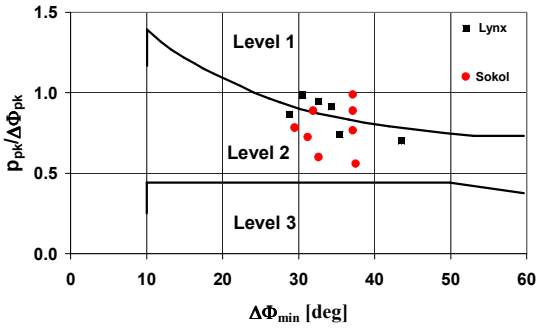

Fig.9 Roll attitude quickness points

Transient Turn

Transient Turn is a very aggressive manoeuvre. It is commonly performed during both flight shows and at a battlefield. It consists of 180-degree change of a flightpath direction in the shortest possible time. This manoeuvre should be performed at 220 km/h and at an altitude equal to or below 61 m both to the right and to the left.

The manoeuvre was performed with the *Sokol*. The control aggressiveness was close to maximal. The roll angle was greater than 75^0. The obtained results are shown in Fig.10. The *Desired* requirements were fulfilled.

Criterion	ADS 33 requirements		Results
	Desired	Adequate	
Time	10 sec	15 sec	≤10 sec
Maintenance of altitude	≤15m	≤60m	≤60m

Fig.10 Results of the *Transient Turn* manoeuvre

Acceleration and Deceleration

This manoeuvre starts from a stabilised hover. The power is rapidly increased to its maximum value. An altitude should be maintained constant during the whole manoeuvre. The maximum airspeed at the end of acceleration stage should be 93 km/h. Next a deceleration is initiated by an aggressive reduce of the power. The peak pitch attitude is occurred just before the final stabilised hover is reached. According to [2] the suggested course of this manoeuvre is shown in Fig.11.

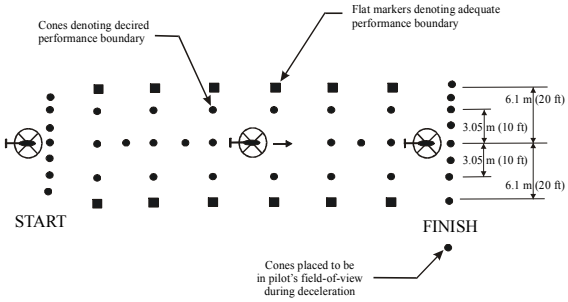

Fig.11 Suggested course for *Acceleration and Deceleration* manoeuvre /Rf.[2]/

A precise execution of this manoeuvre is very important. If the deceleration is too early or too soft an aim of this manoeuvre is not reached - the helicopter could be recognised by enemy. In the case of too late deceleration, the helicopter can be crashed.

Criterion	ADS-33 requirements		Results
	Desired	Adequate	
Minimal airspeed during acceleration	93 km/h	93 km/h	101 km/h
Maximal altitude	≤15m	≤21m	≤15m
Maintenance of lateral track	±3m	±7m	≤3m
Nose-up pitch attitude during deceleration	$\geq 30^0$	$\geq 10^0$	34^0
Maintenance of heading	$\pm 10^0$	$\pm 20^0$	$\pm 6^0$
Time of 95% power achieving	1.5 sec	3 sec	0.5 sec
Time of full collective pitch decrease	3 sec	5 sec	4 sec

Fig.12 Results of the *Acceleration and Deceleration* manoeuvre

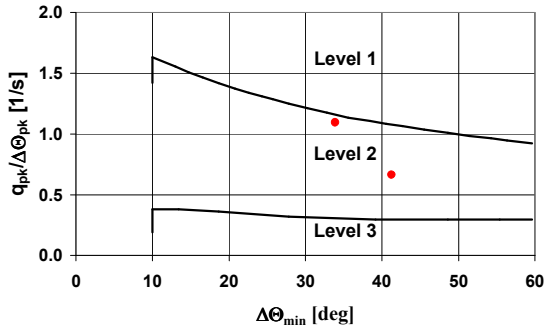

Fig.13 Pitch attitude quickness points

The Sokol reached almost all ADS-33 requirements at the level *Desired*. This is shown in Fig.12. *Pitch attitude quickness* was also determined for this manoeuvre. It was defined as:

$$\frac{q_{pk}}{\Delta\Theta_{pk}} = f\left(\Delta\Theta_{\min}\right)$$

where q_{pk} was the peak angular pitching velocity and $\Delta\Theta_{pk}$ was the pitch angle change. Fig.13 presents the obtained coefficient versus the minimum pitch change $\Delta\Theta_{\min}$. It should be underlined that this manoeuvre was not executed with the maximum aggressiveness. The longitudinal control margin was greater than 40%. It means that the ADS-33 norm can be executed at *Level 1*.

Deceleration to Dash

This manoeuvre can be utilised mainly at a battlefield. If launching of a rocket during a flight is not effective at high airspeed, the velocity should be decreased as quickly as possible. Next the airspeed should be increased again.

According to the ADS-33 norm, this manoeuvre starts from a horizontal unaccelerated flight at 222 km/h. Then the helicopter is decelerated up to 130 km/h. Next it is accelerated until the initial airspeed is again reached. An altitude should be maintained by adjusting of the pitch attitude. The entire manoeuvre should be conducted below 61 m.

The ADS-33 requirements are very demanding but the *Sokol* executes this manoeuvre easily /Fig.14/. Some modifications of pilotage technique are only necessary to shorten acceleration time of power unit during the acceleration phase of flight.

Criterion	ADS-33 requirements		Results
	Desired	Adequate	
Minimal decrease of airspeed during deceleration	130 km/h	130 km/h	133 km/h
Altitude	maintain within ±15m	below 61m	maintained within ≤±15m
Maintenance of heading	$\pm 5^0$	$\pm 10^0$	$\pm 4^0$
Time of full down collective pitch achieving	3 sec	5 sec	2.8 sec
Time of 95% maximum power achieving	2 sec	3 sec	3.4 sec

Fig.14 Results of the *Deceleration to Dash* manoeuvre

Turn to Target

This is one of the most aggressive tasks performed in the case of good visibility. It starts from a stabilized hover at altitude less than 6.1m. A 180^0 turn should be completed in both directions. The final heading tolerance is determined by a sight mounted on the helicopter. This manoeuvre should be executed quickly but also very precisely. A moderate wind from the most critical azimuth or from the rear of the helicopter is permissible. The desired and adequate ADS-33 requirements for this manoeuvre are shown in Fig.15. The results obtained for the *Sokol* helicopter are also presented

in this figure. One can see that the *Desired* requirements are fulfilled.

Criterion	ADS 33 requirements		Results
	Desired	Adequate	
Maintenance of lateral and longitudinal displacement	±1.83m	±3.66m	±2m
Maintenance of altitude	≤15m	≤21m	≤15m
Maintenance of lateral track	±0.91m	±1.83m	≤±2m
Stabilising of final heading	determined by the firing system	$\leq\pm3^0$	$\leq\pm3^0$
Maintenance of heading	$\pm10^0$	$\pm20^0$	$\pm6^0$
Firing solution completion time	<5 sec	<10 sec	<5 sec
Maximal yawing velocity	$\geq60^0$	$\geq22^0$	$\geq60^0$

Fig.15 Results of the *Turn to Target* manoeuvre

Pirouette

This manoeuvre is utilised at a battlefield for visual observation of an intercepted target. This manoeuvre is initiated from a stabilized hover over circumference of a 30.5m radius circle. The nose of the helicopter should be pointed at the centre of the circle at an altitude of approximately 3.05m. A lateral translation around the circle should be accomplished and terminated with a stabilised hover over the starting point /Fig.16/.

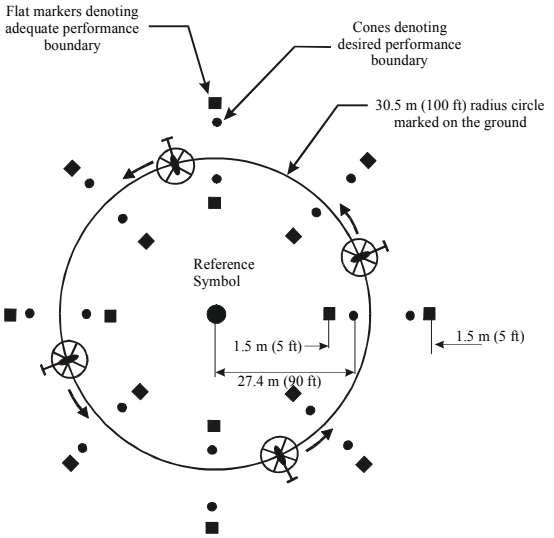

Fig.16 Suggested course for *Pirouette* manoeuvre /Rf.[2]/

Fig.17 presents results from test flights. These flights were executed at windy weather conditions. In spite of this the *Sokol* satisfied the most harsh ADS 33 requirements.

Criterion	ADS 33 requirements		Results
	Desired	Adequate	
Displacement along the radius of the circle	≤±3.05m	≤±4.57m	≤±3m
Maintenance of altitude	≤±1.22m	≤±3.05m	≤±1m
Maintenance of heading	$\leq\pm10^0$	$\leq\pm15^0$	$\leq\pm10^0$
Time of manoeuvre	≤45sec	≤60sec	≤45sec

Fig.17 Results of the *Pirouette* manoeuvre

Bob-up and Bob-down

This is one of most frequently utilised helicopters' manoeuvres at a battlefield. The helicopter starts from a stabilised hover at 3.05m altitude and next bobs up to a defined reference altitude between 12.2 and 15.2m. This altitude is stabilised for at least 2 sec – an attack with fixed guns is simulated. Finally the helicopter is bobbed down to reestablish the 3.05m stabilised hover /Fig.18/.

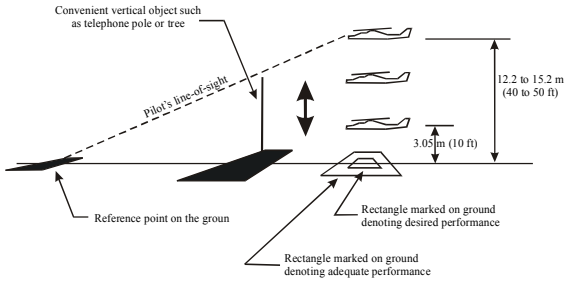

Fig.18 Suggested course for *Bob-up and Bob-down* manoeuvre /Rf.[2]/

Criterion	ADS 33 requirements		Results
	Desired	Adequate	
Maintenance of longitudinal and lateral position	≤±2m	≤±3.05m	≤±2m
Minimal time of stabilised hover	2sec	2sec	2sec
Maintenance of final hover	≤±1m	≤±2m	≤±2m
Maintenance of heading	$\leq\pm3^0$	$\leq\pm6^0$	$\leq\pm4^0$
Maximal time of manoeuvre	10sec	15sec	≤10sec

Fig.19 Results of the *Bob-up and Bob-down* manoeuvre

Desired and adequate ADS-33 requirements and the *Sokol* results are presented in Fig.19. Fig.20 shows the maximum vertical velocity versus the altitude increase. These results are compared with

results of the Puma helicopter. One can see that in this case capabilities of the *Sokol* are better – this manoeuvre was executed more aggressive.

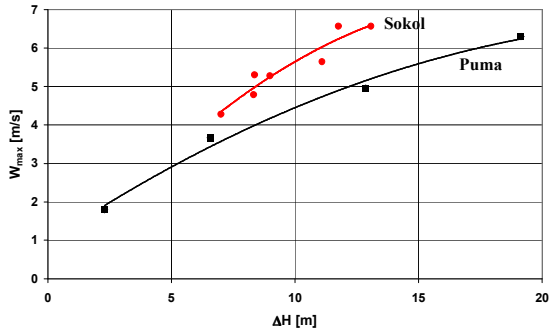

Fig.20 Maximum vertical velocity versus an increase of the altitude

4. Conclusion

Presented selected results shows that the *Sokol* helicopter fulfils most of ADS-33 requirements at *Levels 1* and *2*. It means that its flight characteristics are good and it can be utilised in most of missions in the operational flight envelope. This objective conclusion is also confirmed by the subjective assessment based on the Cooper-Harper rating scale.

Taking into account pilots' opinions and experiences obtained during test flights the thesis can be formulated that some modifications of the pilotage technique will allow fulfilling requirements of the *Level 1* for majority of manoeuvres.

At the end it should be underlined that during the *Sokol* examinations the stress was put on the most difficult manoeuvres and the rotorcraft met all necessary requirements.

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