SEVENTH EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No. 53

MAST MOUNTED VISUAL AIDS

R. D. von Reth
M. Kloster

Messerschmitt-Bölkow-Blohm GmbH
Munich, Germany

September 8 - 11, 1981

Garmisch-Partenkirchen
Federal Republic of Germany

Deutsche Gesellschaft für Luft- und Raumfahrt e.V.
Goethestr. 10, D-500 Köln 51, F.R.G.

MAST MOUNTED VISUAL AIDS

R. D. von Reth

M. Kloster

Messerschmitt-Bölkow-Blohm GmbH
Munich, Germany

Abstract

Initial flight tests with a spherical mock up, having the same shape, weight and moments of inertia as the actual system were carried out on a Bo 105 with two different rotormast extensions (90 and 120 cm). A vibration survey over most of the Bo 105's flight envelope showed vibrational loads which can be tolerated by the actual system.

Investigations of the controllability and stability are also presented. No significant influence on the flight mechanical behaviour of the helicopter was found during the flight tests so far. The major influence being a slight reduction of the maximum horizontal speed.

As a next step the actual stabilized platform with FLIR, TV-camera and a laser range finder was installed on the rotormast. In addition several subsystems used for the display of the video images with superimposed symbology are described. For direct comparison purposes three different systems, Head Up, Head Down and Helmet Mounted Sight and Display will be evaluated. The influence of the rotorplane, vibrational loads and meterological conditions on the performance of the FLIR image is described.

1. Introduction

Presently MBB is carrying out an experimental program with a Bo 105 as a flying test bed sponsored by the German Ministry of Research and Technology.
The goal of the program is the definition of advanced cockpits and visual aids for future helicopters. A number of different equipment manufacturers cooperate with MBB in this program.

Using an extention of the rotor hub for mounting of such a sensor package has the following advantages:

- unlimited 360 deg. view
- no extensive modification of the fuselage structure
- no possible structural and c.g. problems as in a nose configuration
- no interference problems with the pitot/static system in the nose area
- no problems with landing in unprepared terrain as may be the case with an underfuselage configuration
- no visual obstruction for the crew during VFR operation .

The goal of the present program is to investigate the following subjects:

- possible use of such systems during civil missions and operations by government agencies
- modifications neccessary for these systems optimized for various helicopter missions
- different system's configurations tailored to various missions.

The present system is designed for observation purposes such as

- search and rescue
- surveillance (e.g. traffic and border patrol, natural resorces, anti-terrorist operations)

Modified versions of the present system can also be applied for piloting tasks or military applications.

2. Vibration survey with a mock-up

Initial flight tests with a spherical mock-up, having the same shape, weight and moments of inertia as the actual system, were carried out on a Bo 105 with two different rotor mast extensions (90 and 120 cm). Figures 1 and 2 show the test helicopter with a mock up on two different rotor mast extensions. The large size tube with the upper mounting flange for the sensor package is kept stationary by means of a stand pipe. This leads through the rotor hub and the rotor mast to the bottom of the main gear box. On top of the rotor the same bearing used for the swash plate is applied to seperate the upper stationary part from the rotating rotor hub.

Fig. 1: Bo 105 with platform mock up
(90 cm rotormast extension)

Fig. 2: Bo 105 with platform mock up
(120 cm rotormast extension)

Some representative flight test results for vibrations are shown in fig. 3 and 4. Fig. 3 showes lower vibrations for the sphere in the x- and z-direction for the 90 cm configuration whereas in the y-direction this configuration showes somewhat higher values.

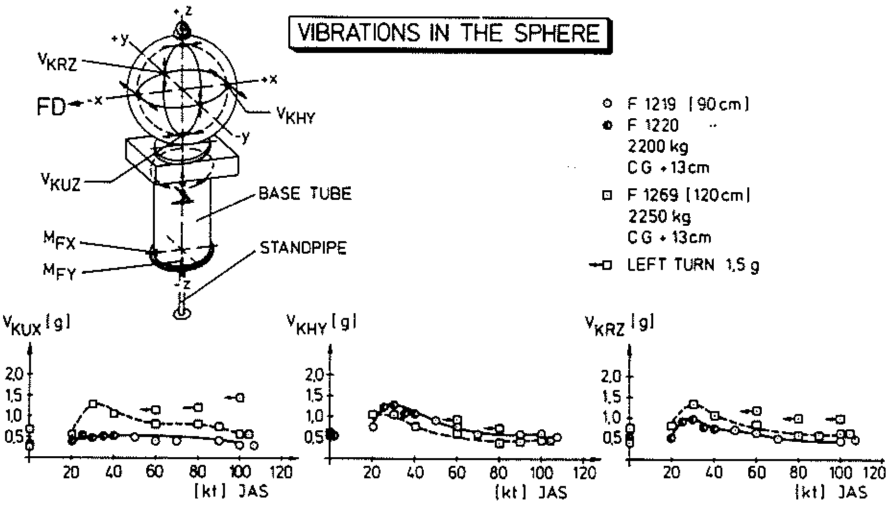

Fig. 3: Comparison of vibrations in the sphere for the two rotormast extensions

Fig. 4 showes measured vibrations in the upper mounting flange of the base tube. Here in all three directions the values are lower for the 90 cm configuration. The values in this plane were of high importance, because here the base of the actual stabilized platform was to be connected. Since these values compared favourably with the limiting values prefered by the manufacturer, an important prerequisit for successfully testing the actual platform with sensor package was fullfilled.

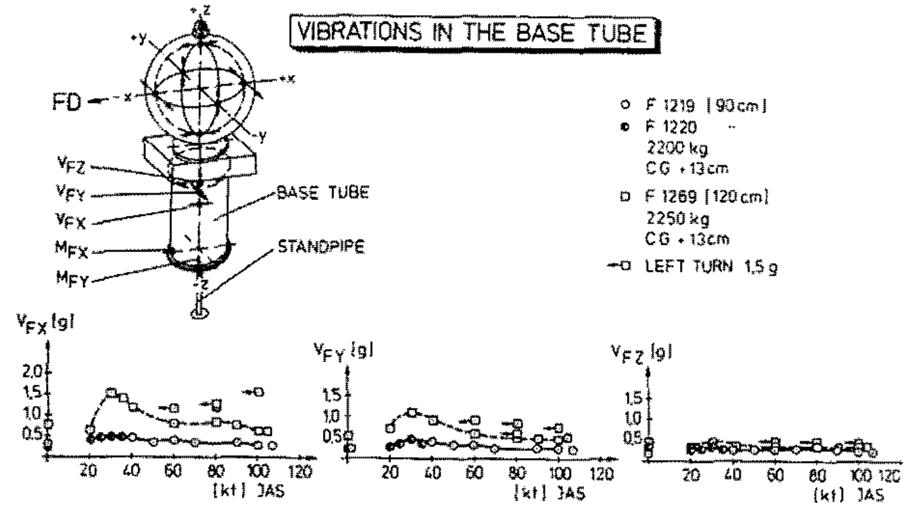

Fig. 4: Comparison of vibrations of the base tube for the two rotormast extensions

To reduce these vibrations even further an additional flight test with shock mounts was carried out. The results of this test are compared with the previous results using a rigid mounting in table 1. This modification reduced the vibrations on the platform in pitch (VKOX) and in yaw (VKVY and VKHY). With shock mounts the base tube is however considerably accellerated in y-direction (VFY) which results in a pronounced role vibration at the sphere. This can also be verified by looking at the time sequences of the measuring points VKLZ and VKRZ showing opposite phase.

All values presented are dominated by the 4-per-rev. contribution (28,3 Hz frequency). This was also confirmed in frequency analyses carried out for the VKOX, VKVY, VFX and VFY. Hardly any low frequency contributions (e.g. natural torsional frequency of the stand pipe apx. 2.7 Hz, or 1-per-rev. 7 Hz excitation) or higher frequency contributions (e.g. tail rotor frequency or 8- or 12-per-rev.) were observed in the vibrational survey.

		TRANSITION (PEAK/2-VALUES [G])		NORMAL FLARE (PEAK/2-VALUES [G])	
		RIGID	SHOCK MOUNTS	RIGID	SHOCK MOUNTS
BASE TUBE	VFX	0,5	1,1	0,4	2,0
	VFY	0,5	4,0	0,8	8,5
	VFZ	0,3	0,4	0,8	0,6
SPHERE	VKOX	1,8	1,2	2,7	2,0
	VKUX	0,6	0,7	0,8	1,2
	VKVY	1,3	0,5	2,4	0,6
	VKHY	1,3	0,5	2,5	0,6
	VKLZ	1,0	2,5	1,9	6,2
	VKRZ	1,0	3,0	1,5	5,0

Table 1: Comparison of maximum vibrations for rigid and soft mounting

It should be noted that the vibrations in the mounting flange of the base tube were rather low with the rigid mounting. Thus it was decided to continue the flight testing with the actual stabilized platform using the 90 cm mast extention with rigid mounting. This allowed keeping the development effort minimal.

3. Flight Mechanics

The primary aim of the programme was the integration and testing of the SFIM Ophelia mast mounted optical system on the MBB Bo 105 helicopter. Consequently, the dedication of test instrumentation to this task limited the measurement capacity available for the flight mechanics considerations, so that theoretical investigations were performed in support of the experimental programme.

3.1 Maximum Forward Speed

Owing to the mast extension and sphere housing the optical equipment, the aerodynamic drag of the total helicopter is increased. Figure 5 shows the helicopter power requirements and engine capacity for the equivalent test height corresponding to a density altitude of z_σ = 5000 ft. (ISA). For comparison purposes, flight test measurements for the standard Bo 105 are given in the diagram and demonstrate good agreement with the theoretical predictions. Measurements with the addition of Ophelia indicate an increase in equivalent drag area estimated to be approximately 0,6 m^2. This is due in part to the greater pitch attitude trim angle and to the cabin roof modification, required to house the Head-Up-Display, adding approximately 0,2 m^2 together with an estimated 0,4 m^2 for the mast extension and spere mounted on the rotor head. This value agrees well with the 3 to 5 ft^2 equivalent drag area estimated by Pitt and Heacock (a) for mast mounted sight systems. The additional drag was found to reduce the maximum continuous forward speed of the Bo 105 with an Ophelia mock-up to 107 kias.

3.2 Trim

Flight investigations with Ophelia showed differences in longitudinal and lateral cyclic control trim requirements compared to the standard Bo 105 (Figure 6). Approximately 1,5° additional longitudinal cyclinc is required at 100 kias, however, a sufficient control reserve of around 25 % is still available for manoeuvering and gust compensation. The collective pitch requirements are slightly increased owing to the increase in drag as previously discussed. The pitch attitude is increased by apx 1° at 100 kias.

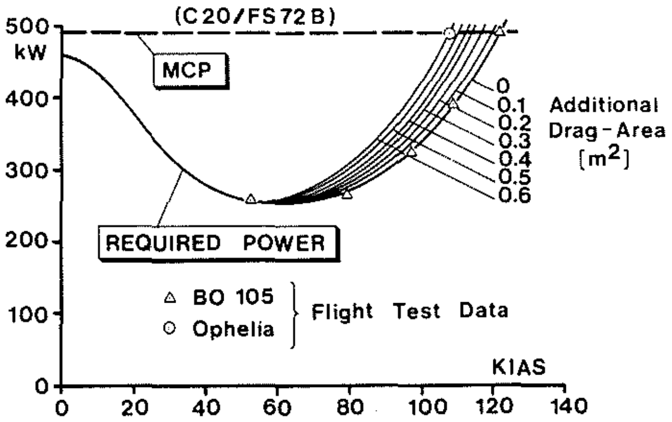

Fig. 5: Horizontal Flight Performance of Bo 105 and OPHELIA

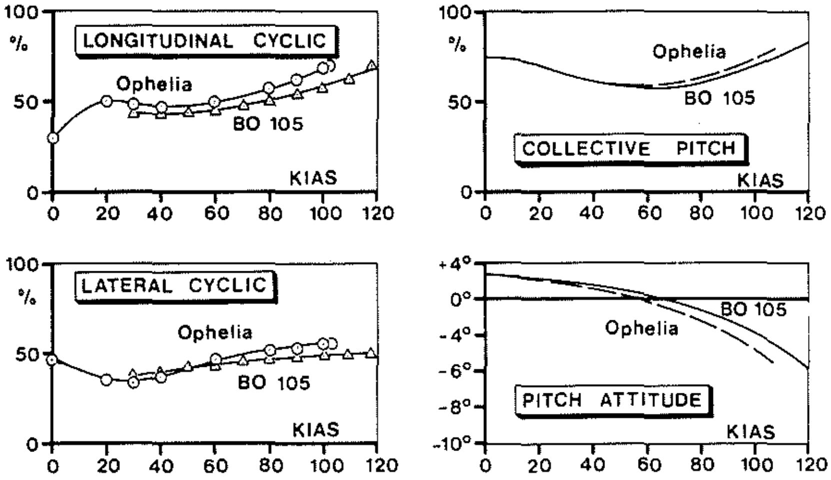

Fig. 6: Trim State of Bo 105 and OPHELIA

3.3 Controllability

The hingeless rotor Bo 105 has been demonstrated to possess excellent control and handling qualities, as typified by the roll and yaw characteristics shown in Figure 7. Both the Bo 105 and the Bo 105 P, with increased roll and yaw inertia, lie well within the limits recomended by Edenborough and Wernicke (b) and fully meet the Mil-H-8501A requirements. The Ophelia system similarly increases the pitch and roll inertia and falls correspondingly between the standard Bo 105 and the Bo 105 P.

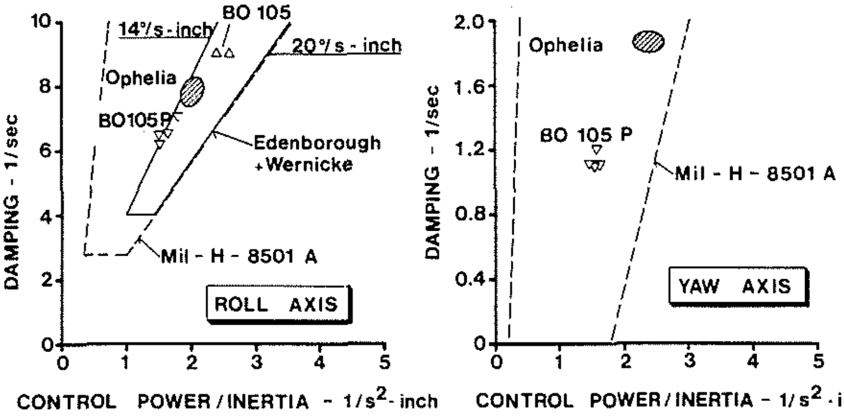

Fig. 7: Control characteristics of Bo 105 and OPELIA

3.4 Stability

Theoretical investigations showed that no detrimental changes in longitudinal stability were to be expected of the Bo 105 with Ophelia compared to the standard Bo 105 configuration. For example, the time to double amplitude was only marginally reduced at 100 kias from 2,42 sec. to 2,36 sec.

Flight test measurements and analysis of the Dutch-roll mode indicated a relative damping of 11 to 12 %, similar to the Bo 105, however, with an increase in frequency from 2,6 rad./sec. to approximately 2,8 to 2,9 rad./sec. The FAA single-pilot IFR requirements (g) stipulate a time to half amplitude to be equal to or less than the period of oscillation for frequencies attained in the Dutch-roll mode. This requirement is equally fulfilled by the Bo 105/Ophelia combination as by the standard Bo 105.

3.5 Rotor Mast Moments

For normal loading conditions (weight and c.g. position), the Bo 105 requires a positive, in the direction nose up, rotor pitching moment in order to trim the level flight case. The Ophelia mast extension tends to increase the rotor hub pitching moment and rotor mast loads which appear as an increase in the rotor mast bending moment. However, since the pitch trim attitude is increased nose downward, the tail-plane itself is more effectively able to balance the trim pitching moment requirements, thereby alleviating the rotor hub loading, so that the effective rotor mast moment is reduced. Measured moment values in the pitch and roll axes at the base of the mast extension are given in Figure 8.

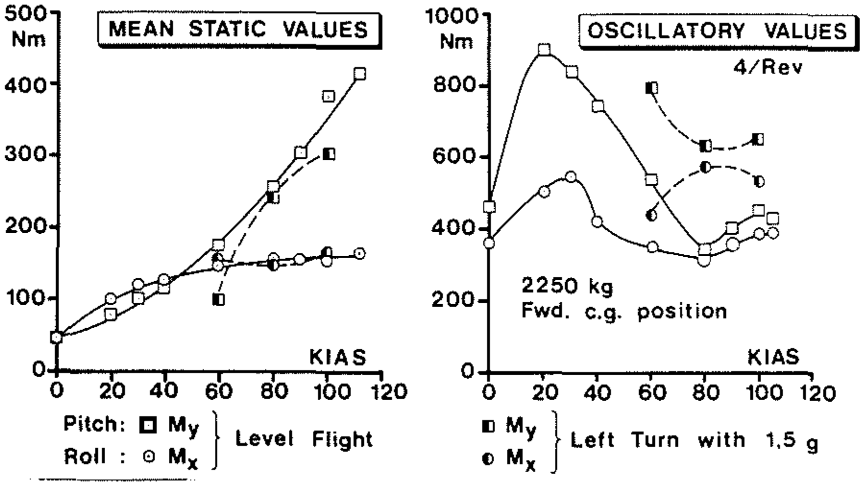

Fig. 8: Measured moments at the base of the mast extension

It can be clearly seen that, as a result of the aerodynamic drag, the mean pitching moment increases as a function of flight speed. Conversely, the mean rolling moment, resulting from the sidewards deflected air flow through the rotor and from the roll attitude, only slightly increases as a function of forward speed. The mean static value in hover is caused by the pitch and roll trim attitudes of apx. 3°. Bank turns up to 1,5 g were found not to significantly increase the static moments.

The oscillatory moments, principally 4-per-rev., are at a maximum in low speed. In 1,5 g turns, the oscillatory values increase but the rotor mast moment remains well within the limits. Theoretical calculations predict that the overall values are less than 1/5 to 1/4 of the permitted maxima.

3.6 Ground and Air Resonance

Before commencing the flight test programme, extensive ground and finally air resonance investigations were performed, which confirmed there to be no significant differences to the standard Bo 105. Figure 9 shows the results of exciting the ground resonance mode through lateral cyclic control inputs of 2,2 Hz and 2,25 Hz respectively. The amplitude of the measured roll rates indicates a natural frequency close to 2,25 Hz, however, as the sketched-in decay envelope serves to demonstrate, the mode is well damped.

Forced excitation in both longitudinal and lateral cyclic at the critical air resonance frequency was found to cause the helicopter response to damp. Immediately the input was cancelled.

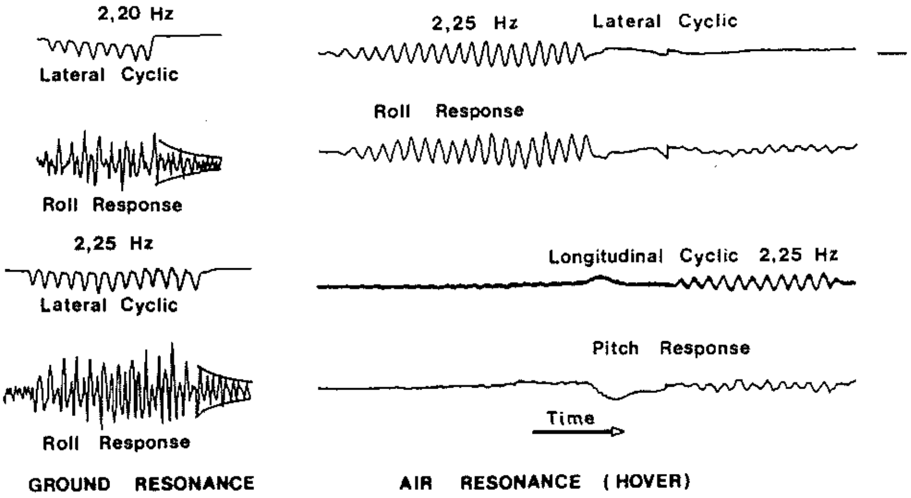

Fig. 9: Ground- and air-resonance of Bo 105-OPHELIA

3.7 Pilot's Work Load

Apart from the slight reduction in the roll control power and damping, resulting from the increase in roll inertia, the pilots assessed the work load with Ophelia to be equal to the standard Bo 105. The marginal increase in the Dutch-roll frequency was, owing to the good damping, not considered by the pilots to add to the pilot activity.

4. Systems installed into the Bo 105

In addition to the stabilized platform with sensor package on the extended rotormast,various systems had to be installed inside the helicopter. For evaluation and experimentation purposes three different display systems will be installed, a Head Up Display (HUD), a multifunction Head Down Display (HDD) and a Helmet Mounted Sight and Display (HMS/D). Presently only the first two systems are installed,however preparation is under way to install a HMS/D using electromagnetic technique to determine the head motion. It is anticipated that this system shall play a major roll during the piloting evaluations rather than during the pure observation missions.

The mass of the parts installed above the rotorhub is apx. 122 kg, whereas all the systems and components (electronic and control units) in the helicopter have a total mass of apx. 71 kg.

4.1 Platform with sensor package

The two axes stabilized platform (provided by SFIM) has the following characteristics:

- diameter apx. 60 cm
- gyro stabilized with two stages
  corse stabilization with torquer, fine stabilization with mirror
- displacement angles ± 120° in azimuth
  − 30°/+20° in elevation
- slew rate apx. 10°/s.

The sensor package contains the following subsystems:

- FLIR camera with advanced technology (provided by TRT)
- TV camera
- Laser range finder

Some characteristic data of these subsystems are listed below.

FLIR

- two field of view 8,1° x 5,4° (x 4)
  2,7° x 1,8° (x12)
- spectral range 8 - 13 µm
- frame rate 25/s
- French common module technology
- cooling of detectors with nitrogen bottle, apx. 2,5 hrs duration.

TV

- one narrow field of view 0,75° (x 50)
- Spectral range 0,5 - 0,9 µm

Fig. 10 shows the platform with sensor package installed.

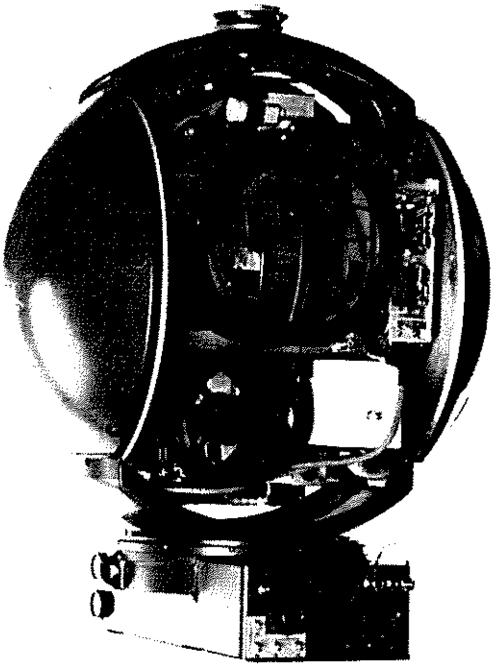

Fig. 10: Ophelia Platform with sensor package

Laser Range finder

- wave lenght 1,06 μm
- pulse duration $25 \cdot 10^{-9}$ s
- peack power apx. 1 MW
- range 150 m - 9900 m
- accuracy apx. ± 5 m

4.2 Display Systems

The two display systems (HUD and HDD) and a Computer symbol generator (CSG) are provided by VDO.

HUD

The HUD was modified to allow the selective display of IR and TV images using raster techniques. Different symbologies can be superimposed. The total field of view is apx. 20°.

HDD

8" monochromatic display with automatically controlled high contrast and brightness. For some of the future tests a similar multicolor display shall be used,in particular in conjunction with the representation of flight management and diagnostic data.

The installation of the two display systems is shown in figures 11 and 12. Fig. 12 shows a special shield attached to the HDD, such that the evaluating test pilot is not distracted by the conventional instruments.

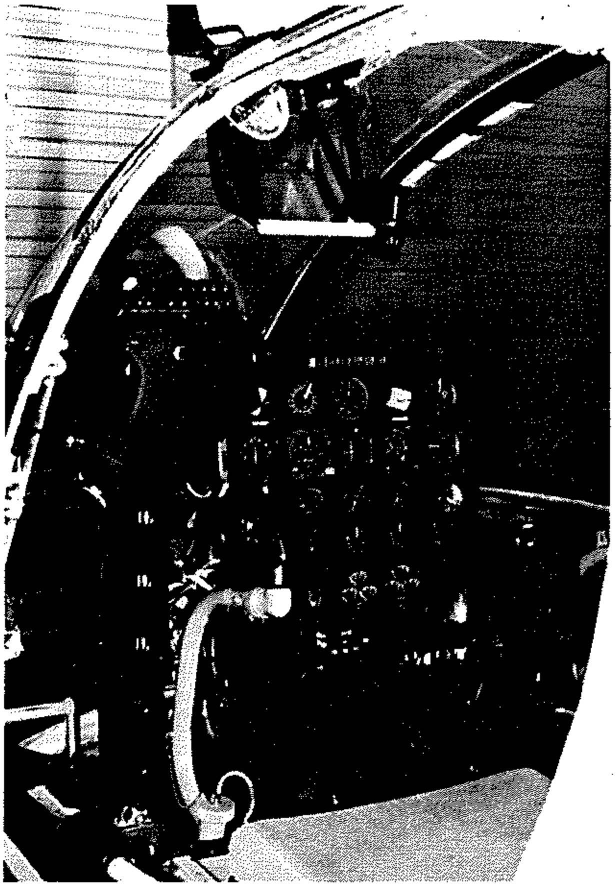

Fig. 11: Installation of the display systems HUD and HDD

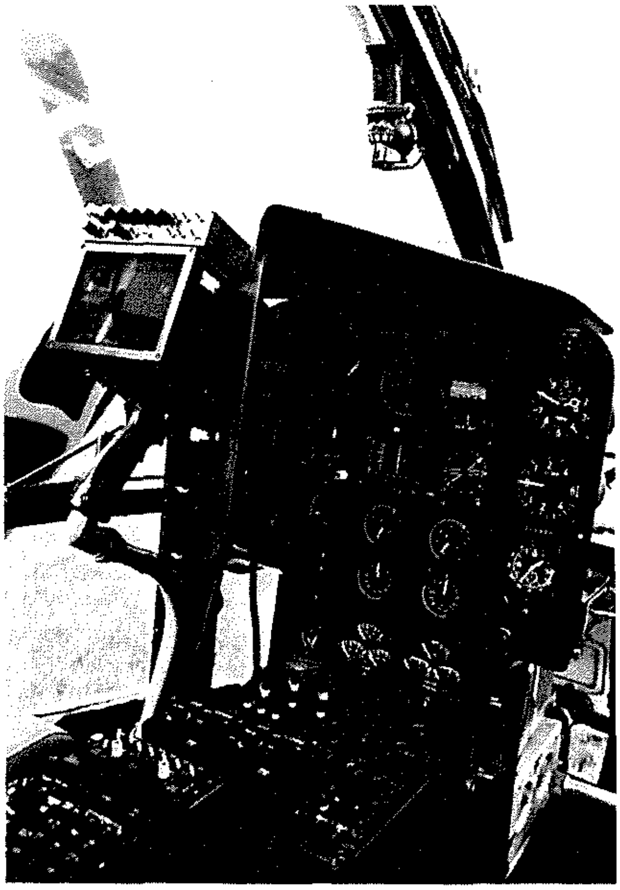

Fig. 12: Arrangement of shielding for the HDD

Fig. 13 shows the Bo 105 helicopter with the actual stabilized platform and the two display systems installed.

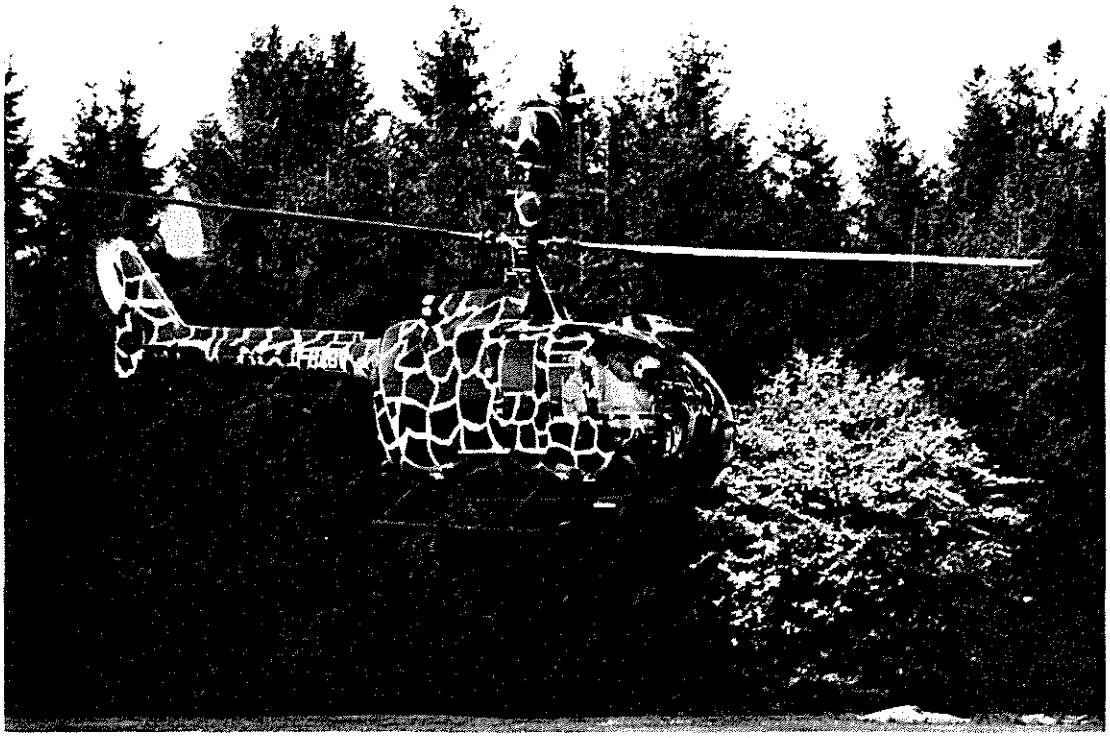

Fig. 13: Bo 105 with rotormast platform and sensor package

CSG

Conditions signals from the helicopter sensors to provide a symbolic representation of these parameters either monochromatically or in colour on a selected display. Simultaneous operation of several different displays is possible.

5. Preliminary evaluation of the FLIR performance

Up to now only a few flight tests with the actual sensor platform have been carried out. In the following some representative FLIR images are presented. Some of the dynamic effects are somewhat difficult to be seen from the fotographs given here. They can be observed much better viewing the actual video tapes.

Figure 14 shows the influence of the rotor blade motion when looking through the rotor plane downwards. The dark diagonal disturbance of the wooden frame shown,represents one rotor blade. The position of the rotor blade does not remain stationary,thus the over all impression of the scene is hardly influenced. The individual rotor blades are noted as minor moving disturbances only.

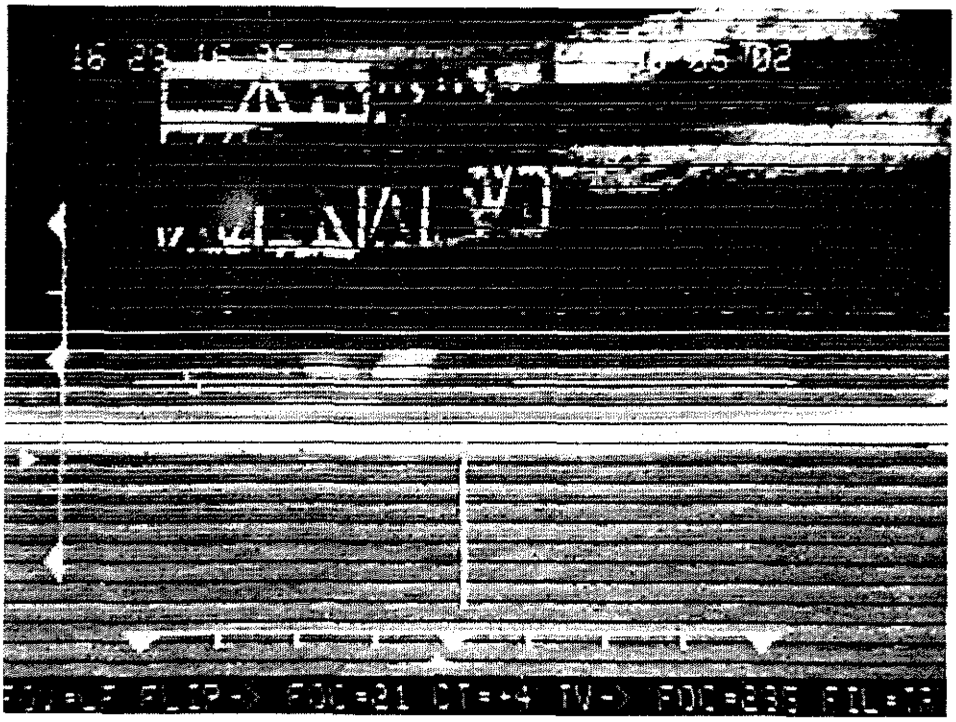

Fig. 14: Influence of rotorblades when looking through the rotor plane

The next figure 15 gives an example of the surprisingly large range obtained with the FLIR system under favourable weather conditions. The structure to be seen on the figure is the Munich TV tower at a distance of apx. 16 km.

Example for an (high contrast) image with high contrast and resolution is shown in figure 16. This picture was taken during day again under rather favourable conditions. Note that it is nearly possible to read the time shown on the clock of the church tower.

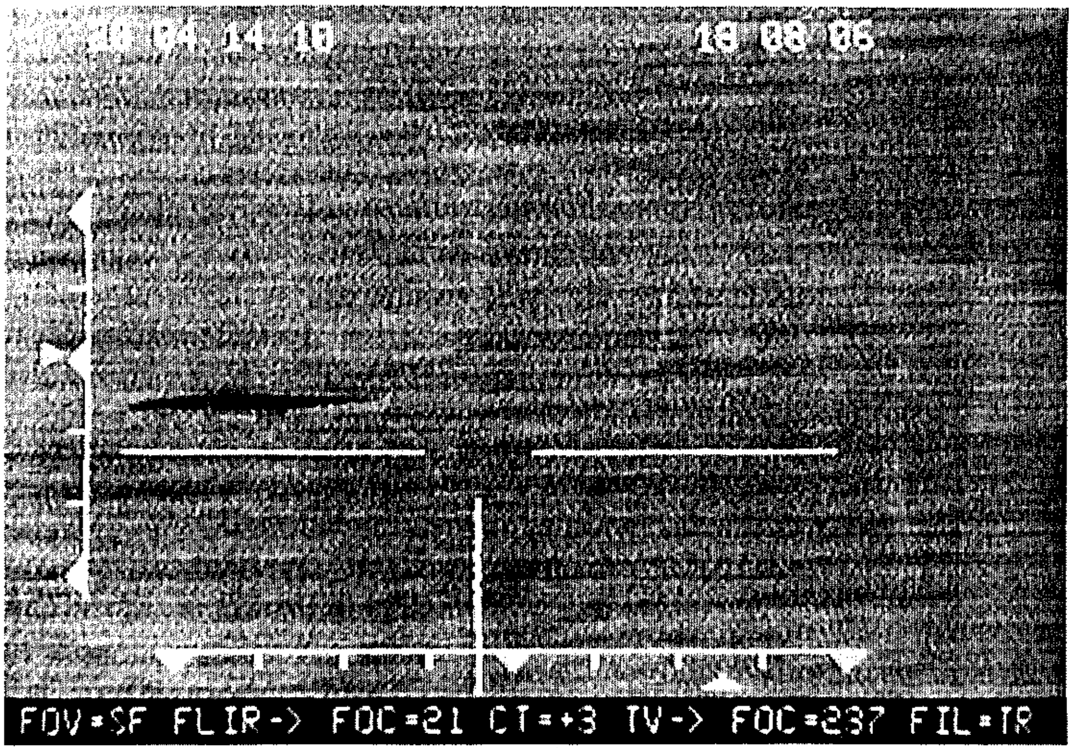

Fig. 15: Example for large range of the FLIR system under favourable weather conditions (Range of TV tower apx. 16 km)

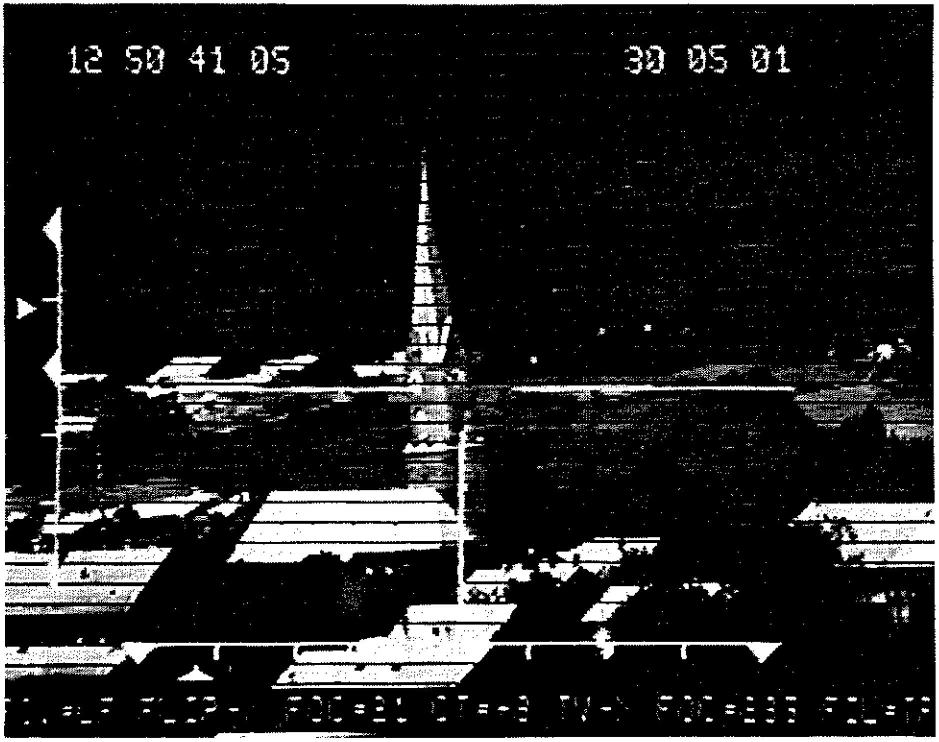

Fig. 16: Example for the high resolution performance of the FLIR system (Range apx. 800 m)

In contrast already in the early tests it was also confirmed that there are some rather unfavourable weather conditions (clouded skies and rain for a longer period) when the performance of the FLIR camera is degraded drastically. Figures 17 and 18 show the same object under favourable and unfavourable weather conditions. Even within the short distance indicated hardly anything can be recognized on figure 18. This picture was taken in the morning during rain after it had rained during the proceeding night. The visual range was still apx. 4 km.

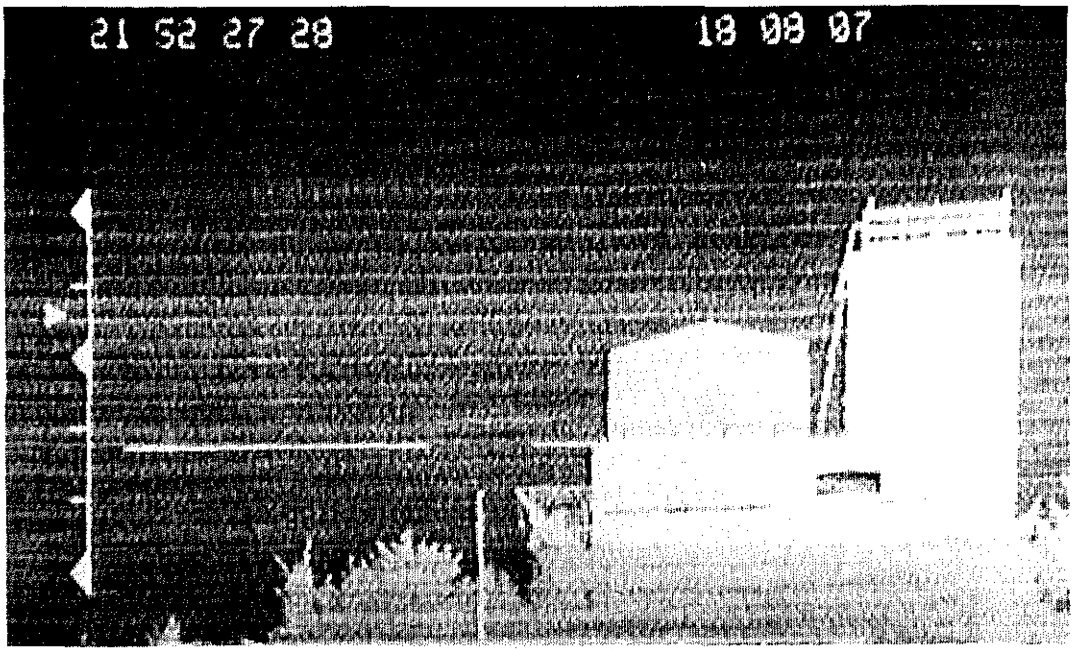

Fig. 17: Object within short range under favourable weather conditions (Rage apx. 230 m)

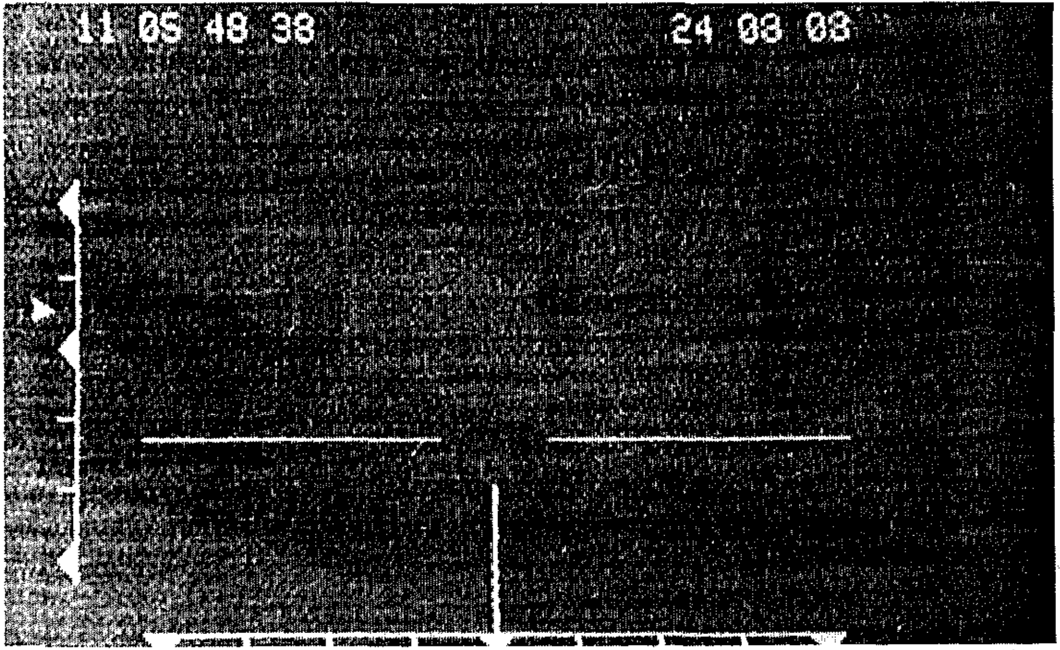

Fig. 18: Same object as in Fig. 17 under unfavourable weather conditions (rain for several hours during the night and still raining)

This series of FLIR-images is concluded by fig. 19 which showes a number of vehicles and superimposed an initial exampel of some of the symbologies to be used during the flight tests. Basicly 3 different symbologies.will be investigated. These being hover, transition and cruise. Emphasis was placed upon not to overload the different symbologies by restricting the number and size of the symbols to be used. The initial example show still some deficiencies like not enough damping, which will be optimised during the following tests.

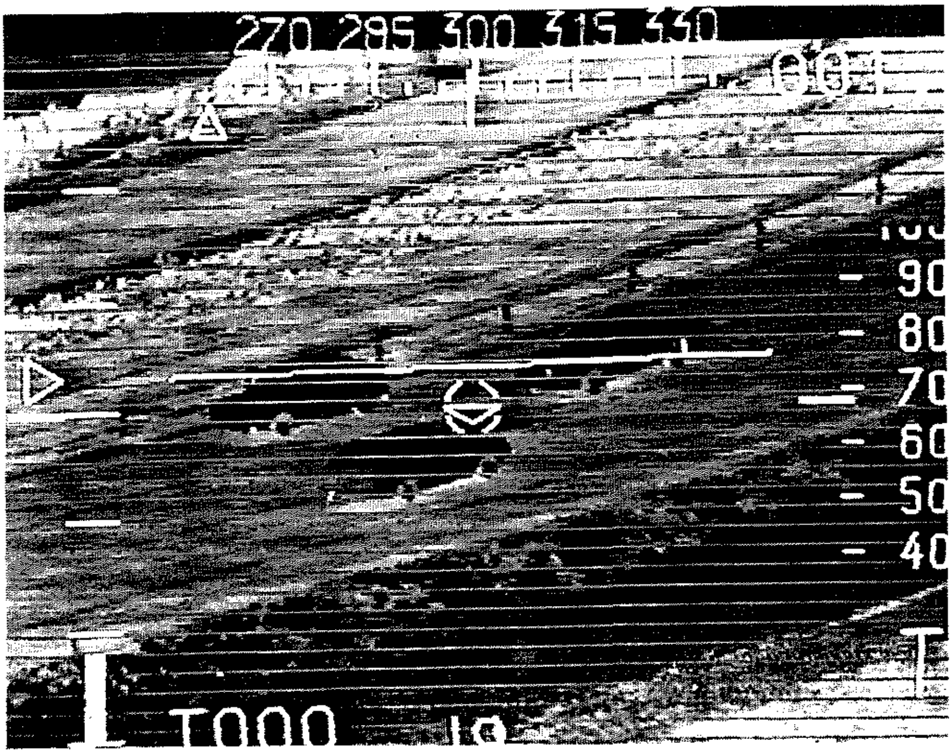

Fig. 19: FLIR image superimposed with a representative symbology

The preliminary results show that it is most unlikely that one electro-optical sensor shall be adequate for different operations under extreme weather conditions. It is more likely that a combination of different sensors has to be adopted to various operations.

6. Summary

The feasibility of operating a stabilized platform with a sophisticated sensor package on an extension of the rotor hub has been demonstrated convincingly. The mass above the rotor hub was apx. 122 kg, thus allowing for the first time to include a high performance FLIR camera in the sensor package. The measured vibrations were found to be well within the limits tolerable for the stabilized platform. No unfavourable effects on the flight mechanical behaviour of the Bo 105 was observed besides a moderate reduction of the maximum horizontal speed. Initial test results show excellent resolution and range performance of the FLIR camera under favourable weather conditions (pronounced temperature differences). Under unfavourable weather conditions, (e.g. in the morning after several hours of rain and still raining) a significant degradation in the performance of the FLIR camera was observed.

In future tests the evaluation of FlIR and TV cameras including LLLTV will be continued in more detail for observational and piloting tasks. Goal of the experimental programm is the definition of visual aid combinations tailored to different mission profiles.

7. References

(1) R. Thoma
Boden- und Flugmessungen mit OPHELIA
Holzatrappe ohne shock mounts auf Bo 105-S1
MBB, TN-DE 243-2078

(2) R. Thoma
Boden- und Flugmessungen mit OPHELIA
Holzatrappe mit shock mounts auf Bo 105-S1
MBB, TN-DE243-2089

(3) R. Thoma
Flugversuche mit OPHELIA-Atrappe
auf verlängertem Tubus
MBB, TN-DE 243-2224

(4) H. Müller
"OPHELIA" Schwingungsverhalten Holzattrappe
mit starren und elastischen Verbindungselementen
MBB, TN-DE 132-27/80

(5) H.D. Böhm
Hubschrauber Helmsichtgeräte (HMS)
Systemuntersuchung
MBB, TN-DE 235-17/81

(6) R.D. von Reth
Controls and Displays for All-Weather
Operation of Helicopters
AGARD, 58th FMP Symposium,
Paris, April 1981, Paper No. 11

(7) Pitt, D.M., Heacock, F.E. Advanced Scout Helicopter Flying Qualities Requirements, How Realistic are they?
35th Annual National Forum, AHS 1971, 79-28 Washington

(8) Edenborough, H.D., Wernicke, K.G. Control and Maneuver Requirements for Armed Helicopters
20th Annual National Forum, AHS, 1964 Washington

(9) FAA Airworthiness Criteria for Helicopter Instrument Flight, 15. Dez. 1978