Calculation of Flare trajectories on rotorcraft and comparison with trials

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1 Overview

Due to the integration of a modern Integrated Self Protection System (ISSYS) into the Cougar Mk. 1 helicopter, the challenge was to guarantee safe flare separation from the helicopter. Our approach to fulfil this requirement was to use modern comprehensive CAE/CAD tools for simulation and visualisation.

On rotorcraft, contrary to fix wing fighters, the separation of the flare is very important for the effectiveness of the countermeasures. Calculating and improving the system performance against the most prominent threats for the Swiss Airforce Transport Helicopter was an additional aim of the simulation tools.

The Swiss authorities (DPA) have qualified the integration of the ISSYS by RUAG Aerospace into the 10-ton class transport helicopter of the Swiss Airforce (Cougar Mk. 1). This paper addresses the development effort of RUAG Aerospace in tools and processes developed with certification board (Swiss Defence and Procurement Agency).

2 Safe separation from rotorcrafts

In order to be safe, the helicopter must have a certain minimum distance from the flare. This minimum distance seen from the seeker head of the missile must be provided for all relative directions of attack.

The speed of a rotorcraft is quite low. Thus, the relative speed between the helicopter and the flare is also smaller than for a fighter. It can be concluded, that the location for flare dispensing, the ejection angle and the dispensing frequency are very important for rotorcraft.

3 Main Threat for rotorcraft

For the Swiss Transport Helicopter, shoulder launched IR guided missiles, so called MANPADS, were identified as the main threat. For this threat there are two main difficulties: first; very short warning time and second; helicopter against missile kinematics.

Example showing a typical combat scenario: Time from firing the missile until hit is very short (i.e. 2.5 seconds)

4 Creating a 3D model of a helicopter

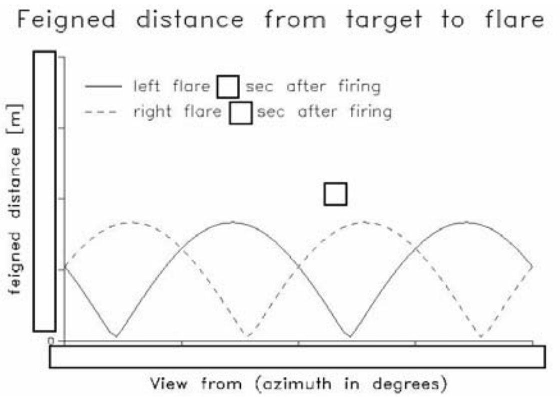
The surface of the 1:1 model of the Super Puma was measured with a special optical tool. The result of this analysis is a point grid in X, Y and Z direction. The points were exported to CATIA and dressed with normal 3D functionality. It is very critical in this process to reduce the measured surface data (14 Gigabytes) to an amount that enables CAE tools to handle a complete helicopter model.

The result is an exact 3D surface with an overall accuracy of approximately 2 mm. An accuracy of 0.3 mm is achievable in special regions. The furnishings (landing gear, rotor head, rotor blades …) were added as solid models.

Super Puma while optical measuring

5 Effectiveness of Countermeasures

In a separate study the effectiveness of the flares was analysed, indicating that it is critical from which side of the helicopter a flare is fired. This depends, amongst other things, on the flight manoeuvre of the target-helicopter and from the direction relative to the helicopter an attack is threatening.



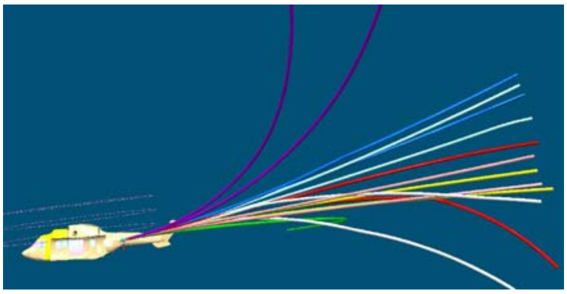
Example showing the feigned distance between target-helicopter and flare as seen from an attacking enemy

6 Dynamic flight envelope

Flight tests were undertaken in the entire flight envelope for identifying the most critical manoeuvres. For the main rotor these were a so-called “hard turn” manoeuvre and for the horizontal stabiliser / tail rotor the “hover turn”. These two manoeuvres define the maximum pointing of the countermeasure dispensers.

7 Flare separation calculation program

A simulation program to calculate flare separation from rotorcrafts was developed. This program was designed to establish a safe separation as well as to find the optimal position at the rotorcraft for the chaff/flare pod and the firing direction of the flares. Safe separation must be possible in the entire envelope of the rotorcraft. In a first step, several test flights were undertaken with a specially equipped helicopter for recording the normal accelerations and attitude of the vehicle (heading, roll and pitch angle) versus time at extreme flight manoeuvres. This data was then used for calculating the flight path and the attitude of flight of the helicopter. As far as the aerodynamic effect of the helicopter on the flares is concerned, only the downwash of the rotor was taken into account. The influence of the flow displacement by the fuselage is negligible as the flares leave the immediate influence of the helicopter in a split second. Even the downwash of the rotor is almost negligible. The flares themselves do not have a well-defined aerodynamic characteristic. They are treated as a mass that decreases with time correspondingly to the burnout speed and having a time dependent drag only. The initial velocity, still being within the flare specifications, can be between about 25 m/sec up to about 60 m/sec. Shortly after firing, they tend to turn over and therefore a remarkable random dispersion around the calculated flare trajectory has to be expected.



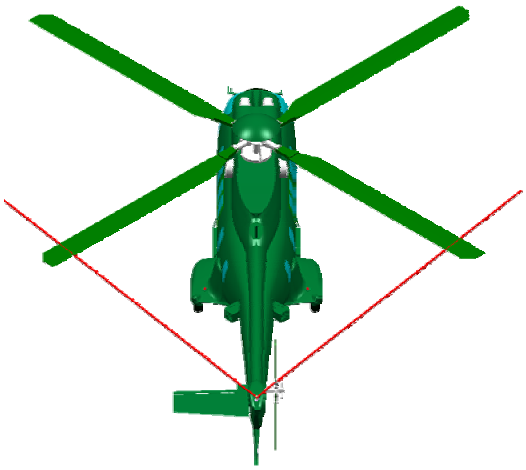
Calculated flare trajectories for different flight manoeuvres: same colour corresponds to same manoeuvre with minimal or maximal initial flare velocity

8 Flight simulator

For visualising the flare separation during flight manoeuvres an interface between the flare separation program and a CATIA based kinematics module was developed.
Using this tool permits the creation of short video sequences and safe distances can easily be measured and analysed by standard capabilities of CAE tools.

9 Measurements of rotor blade movements

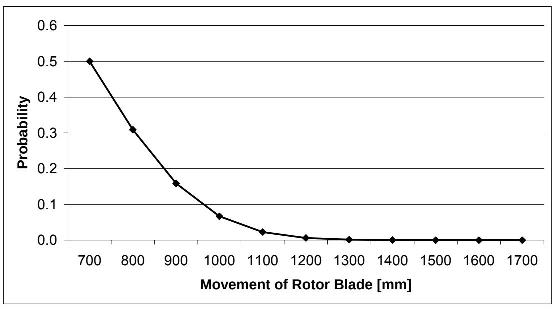
In several flight tests rotor blade movements were recorded by a video camera which was mounted on the tail boom.



Lines of sight of the video camera.

The recorded pictures were manually interpreted with the help of a video recorder, a monitor and a previously prepared scale. The evaluation of the videotapes gave the following results:

- There is no obvious law for the rotor blade movement. This means: the maximal rotor blade movement can be at every possible azimuth angle.
- Some manoeuvres with high movements are (peak value examples):
  Lateral translation ≤ 912 mm
  Autorotation entry ≤ 1046 mm
  Slope landing ≤ 1281 mm
- The maximal movement is at slope landing, which is not considered as real flight manoeuvre. At every actual flight manoeuvre the movement of the rotor blades was never greater than 1050 mm.
- For the safety analysis we translated these results in a statistical distribution: Main value = 700mm with a standard deviation (δ) of 200mm.

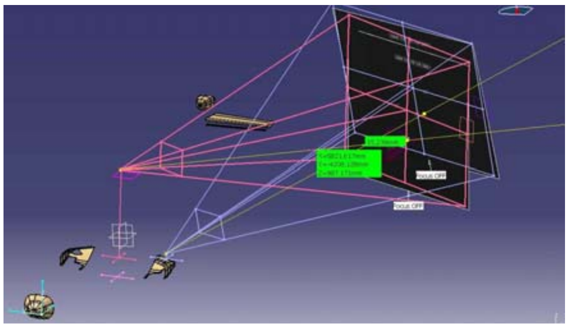


Statistical assumption for the rotor blade movement

- This statistical view is absolutely correct, because:
  A collision of a flare with the horizontal stabilizer, main or tail rotor is nearly impossible and only with statistical methods can the possibilities easily calculated.
  A collision of a flare with the stabilizer or the rotors is not catastrophic and the heat of a flare does not cause significant damage to the helicopter structure.

10 Measurements of real trajectories

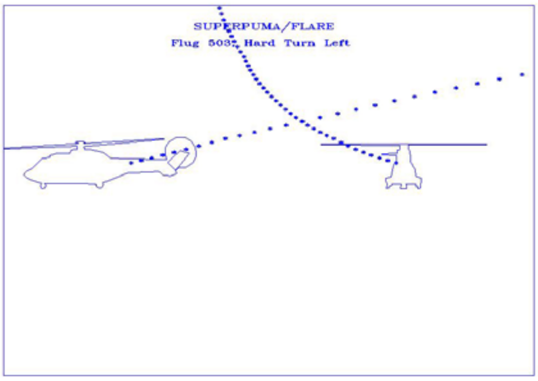
Two video cameras were mounted on the outer skin of the helicopter: one on the main landing gear fairing and the other in the near of the main rotor head. With these two cameras and the onboard measurement system the flare shots and the flight data were recorded. The location and the line of sight of the cameras were represented in the CATIA. The video pictures were also imported into CATIA. With the help of the superimposing of the two frames it is possible to determine the real flare position. Of course the video cameras must be time synchronised.

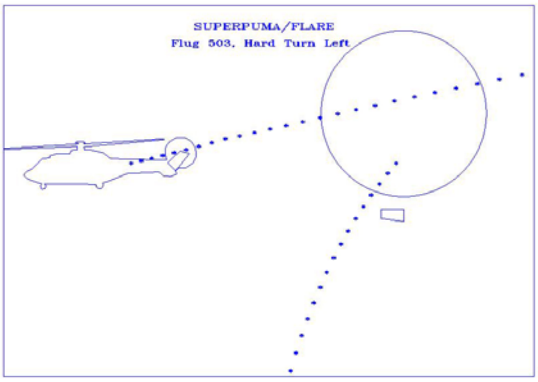


Superimposing of frames in CATIA.

11 Statistical analysis

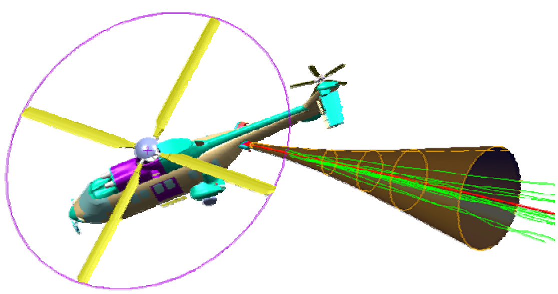
For the critical manoeuvres real flight manoeuvres were used and the flare separation was calculated with the minimal start velocity of 25 m/s. With these parameters we obtained the following **reference curves**.





Reference curves for hard turn

For the determination of the **scatter cone**, several flare trajectories were measured and compared to the reference curve.



Measured trajectories (green) compared to the reference curve (red) with scatter cone (orange).

The standard deviation from the reference curve was calculated at shooting distances of 5, 10 and 15 meters. The calculated reference curve is the centre. For the calculation of the scatter cone the standard deviation was multiplied by 3, which means 3 standard deviations.

The standard deviation includes the following variances:

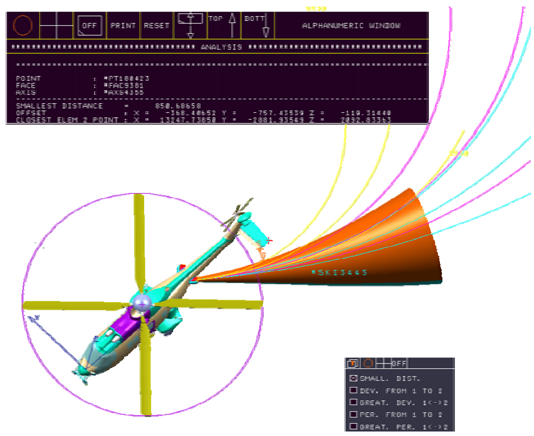
- Accuracy of the method.
- Scattering of the start velocity.
- Scattering of the shooting position.
- Movement of the helicopter.

The **safety cone** was calculated at a shooting distance of 0, 5, 10 and 15 meters. It's consisting of the scatter cone (3xσ), the accuracy of the installation (cone with a several degree opening angle) and the shooting position (form of a cylinder).

Shooting distance	Diameter of Safety Cone
0 m	300 mm
5 m	1738 mm
10 m	3944 mm
15 m	6510 mm

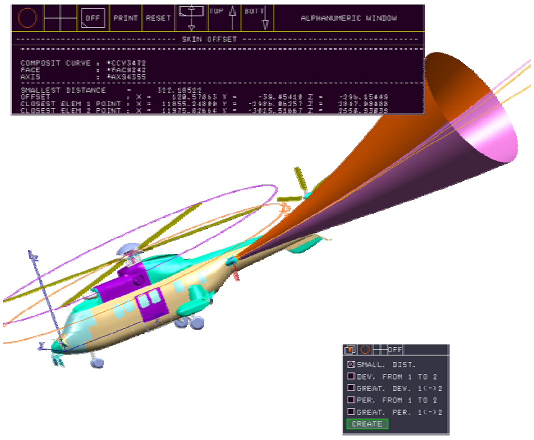
Calculated safety cone for the reference ammunition

The safety cone was laid over the critical reference curves. The minimal distance between the horizontal stabiliser and safety cone, left side, and between the tail rotor and safety, right side, were analysed by CATIA.



Safety distance for the horizontal stabiliser (hover turn).

The same analysis was performed on the main rotor with the hard turn reference curve.



Safety distance for the main rotor blades (hard turn).

For the reference curves the analysis gave the following safety distances (examples):

Reference Curve	Additional Safety Distance
Hover turn (v_0=25 m/s; yaw=50°/s)	324 mm
Hover turn (v_0=25 m/s; yaw=70°/s)	**35 mm**
Hover turn (v_0=45 m/s; yaw=70°/s)	442 mm
Hard turn (v_0=25 m/s)	78 mm
Hard turn (v_0=45 m/s)	**22 mm**
Hard turn (V_0=65 m/s)	37 mm

12 Qualification

The whole ISSYS- system was qualified according to civil and military standards. It was proven, that the ISSYS does not degrade the helicopter systems and that the helicopter systems do not degrade ISSYS. The proper functionality of ISSYS and all the interfaces to the helicopter systems were also shown.

Concerning the counter measures dispensing system (CMDS), the qualification focused on the following topics:
The ammunition itself was qualified with ground tests.
The structural integrity of the dispensers was analyzed for static and dynamic loads.
Simulations showed safe distances between the flare trajectories and the helicopter parts.
Flight trials were used to demonstrate the validity of the analyses and the simulation.

A gradual opening of the flight envelope was performed.
The first firings of flares were done with the helicopter on ground, later during hover, then straight flight and finally with the most severe maneuvers. The important parameters of the maneuvers were increased by steps.

A relatively complex effort was performed to compare the tests with the simulation. The comparison between the simulation and the measurements were very good. These results allow a reduction in the test effort for future ammunitions or helicopters using the qualified simulation and analysis tools.

13 Conclusion

As a result of these developments and investments in engineering and simulation tools and qualification processes, the efforts required for qualification further ammunitions or new positions could be significantly reduced.

Our estimation shows that the number of flight hours for future improvements to the system can be reduced by 80 %, which means approximately 5 flight hours instead of 25. This will causing a significantly large economy in finances of future projects involving such system approvals.

In addition, the flight simulator is a perfect base for analysing the effectiveness of countermeasures against specific threats. Further functionality is planned to simulate the IR behaviour of the helicopter in interaction with deployed flares. We will also investigate the possibility of simulating a combat scenario with an approaching missile.