First Steps towards the Certification of IAR-330 Puma Naval for Helicopter-Ship Operations

Sketches from the Work of 'Romanian- Dutch Centre of Knowledge in Aeronautics'

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Abstract: The Romanian Navy has acquired two Royal Navy Type 22 frigates and plans to operate from these ships with the IAR 330 Puma helicopter. The IAR 330 Puma is a Romanian built version of the Aerospatiale (now Eurocopter) SA 330 Puma helicopter. The Type 22 frigates have the flight deck equipped with a grid at the landing spot for application of a helicopter deck lock system (originally for the Lynx helicopter). The question was posed whether the Puma helicopter can be operated from/to this type of frigate and, if so, what were the limitations will be. The aim of the present paper is to give a first insight into the capabilities of the IAR-330 Puma Naval helicopter to be adapted for helicopter-ship operations. The paper will follow systematically the steps undertaken in the "Romanian-Dutch Centre of Knowledge" project (2004-2006) building "flight deck clearance diagrams" and a simulation model for off-line analysis.

Abbreviations

dof	degrees of freedom	MTRLA	Main and Tail Rotor Landing Area
FFLA	Forward Fuselage Landing Area	NATO	North Atlantic Treaty Organisation
HRP	Helicopter Reference Point	ODE	Ordinary Differential Equation
IAR	Romanian helicopter manufacturer	TRFC	Tail Rotor Flying Clearance
MRFC	Main Rotor Flying Clearance	WLA	Wheel Landing Area
IAR	Romanian Aeronautic Industry		

INTRODUCTION

In 2004 the Dutch Ministry of Economic Affairs engaged the aeronautical industry and research laboratories from Romania and The Netherlands to join the "Romanian-Dutch Centre of Knowledge in Aeronautics" and defined for both countries topics of interest in aeronautics. One of the topics of immediate interest for this centre appeared to be related to the subject of the certification of the 2004 Romania adhered to the NATO structures and started to adapt its infrastructure to these international standards. For this, the Romanian Navy acquired two Royal Navy Type 22 Batch 2 frigates - “Regele Ferdinand” (ex- Her Majesty’s Ship Coventry) and “Regina Maria” (ex- Her Majesty’s Ship London)- planning to operate from/to these ships with the IAR 330 Puma helicopter. In detail, the frigates flight deck is equipped with a grid at the landing spot for application of a helicopter deck lock system (originally for the Lynx helicopter). A picture of the “Regele Ferdinand” and some relevant dimensions of the helicopter flight deck and hangar are given in *Figure 1* (the data on the ship’s helicopter flight deck were obtained from “Jane’s Fighting Ships”.

DIM.	METRES	LOCATION
A	12.6	FLT DK WIDTH AT LANDING CIRCLE
B	23.2	FLT DK LENGTH
C	17.0	HANGAR LENGTH
D	8.36	HANGAR WIDTH
E	6.35	HANGAR DOOR WIDTH
F	6.3	HANGAR DOOR HEIGHT
G	3.1	HEIGHT OF GPI ABOVE FLT DK
H	4.71	HEIGHT OF FLT DEK ABOVE WATER LINE
J	6.66	AFT EDGE OF FLT DK TO GRID AND CIRCLE CENTRE
K	5.0	INTERNAL DIAMETER OF CIRCLE
L	1.4	LENGTE OF ATHWARTSHIPS EXTENSION (SEA KING)
M	5.7	CIRCLE CENTRE TO ATHWARTSHIPS LINE (SEA KING)

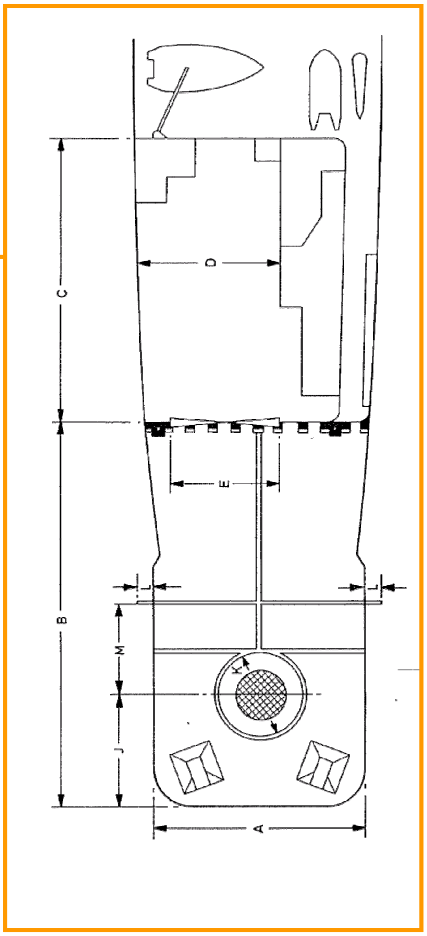

Figure 1. Relevant dimensions of the flight deck and hangar of the Type 22 frigate

The IAR 330 Puma is a Romanian built version of the Aerospatiale SA 330 Puma helicopter (see *Figure 2*). It is a twin engine transport helicopter with a maximum take-off mass of 7400 kg. The main rotor blades of the Puma can be folded manually to facilitate storage in a ship’s hangar. The tail section is not foldable. Some relevant helicopter dimensions are given in *Figure 2* (the data on the IAR 330 Puma helicopter were obtained from the Romanian Air Force, “Jane’s All the Worlds Aircraft”, and IAR documentation). The Helicopter Reference Point (HRP) is also shown in this figure (see the red line). Normally, the deck lock system location is chosen for the Helicopter Reference Point (HRP)[1], however the Puma helicopter is not equipped with a deck lock system, so

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[1] After the investigation was completed, new information revealed that the IAR Puma helicopter was modified to be equipped with a deck lock system between the main undercarriage units. As a result, the helicopter reference point should be changed to the deck lock position, approximately 1.3m behind the main rotor axis.” As a result, the calculated flight deck clearance diagrammes will move forward. However, the conclusions of this investigation still hold.

the main rotor axis is selected as HRP. The main rotor blades of the Puma can be folded manually to facilitate storage in a ship’s hangar.

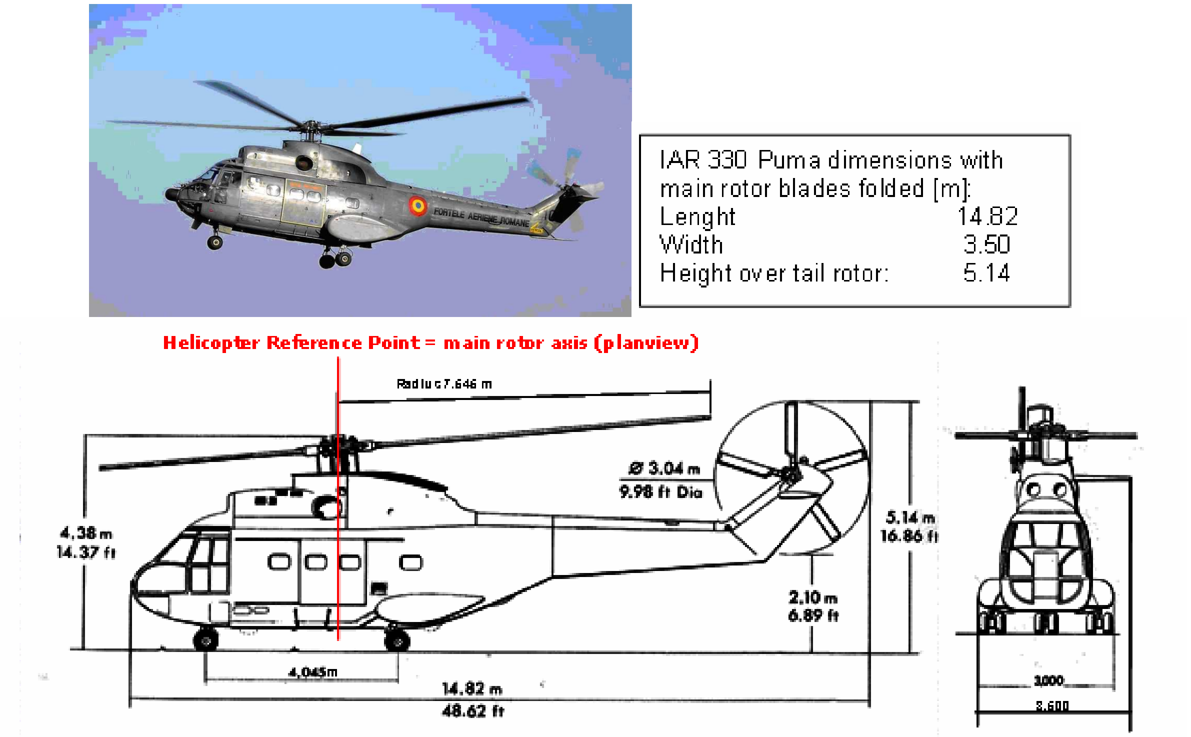


Figure 2 Relevant dimensions of IAR 330 Puma helicopter

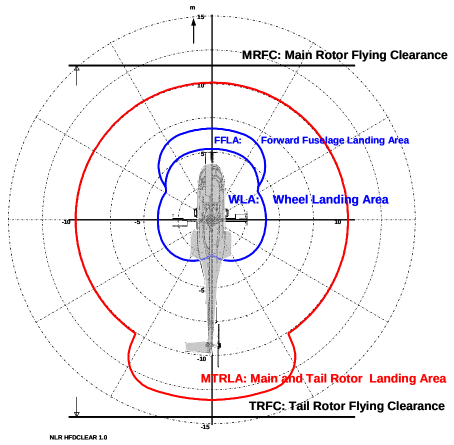
Since the Puma was originally not designed for naval operations, research was conducted on the possibilities and the limitations of using the IAR 330 Puma Naval for shipboard operations. The aim of the present paper is to give a first insight into the capabilities of the IAR-330 Puma Naval helicopter to be operated from/to this type of frigate and if so, what limitations would have to be imposed to such operations. The paper is structured as follows:

- Section 1 presents the flight deck clearance diagrams;
- Section 2 discusses the developed integrated simulation model;
- Section 3 contains the fist conclusion and the next steps to be undertaken.

1. FLIGHT DECK CLEARANCE DIAGRAMS IAR 330 PUMA –TYPE 22 FRIGATE

1.1 General definition for Flight Deck Clearance Diagram

During landing and take-off with a helicopter on a ship, the touch-down position, helicopter heading and airborne flight path are subject to a certain degree of scatter. This scatter is strongly influenced by sea state. With increasing sea state, ship motions are larger due to increased wave height and helicopter motions are larger due to a higher turbulence level caused by higher wind speed [Refs. 2, 3]. The result is increased scatter of the touch-down position, heading and airborne flight path of a helicopter. Based on statistical data and required assumptions potential locations of particular helicopter parts on or above the flight deck can be identified. In a helicopter flight deck clearance diagram curves encompassing these locations are drawn. The result consists of areas projected on the flight deck which will (with a predefined uncertainty) include the particular helicopter parts. Below these helicopter parts a maximum allowable obstacle height is prescribed by regulations of NATO naval forces [Ref. 2]. An example is given in *Figure 3*. The origin of the axes is called Helicopter Reference Point (HRP). The blue lines encompass the possible location on the flight deck of the helicopter undercarriage, the Wheel Landing Area (WLA), and the location of the forward fuselage, the Forward Fuselage Landing Area (FFLA). Below these areas a maximum obstacle height of 0.01 m is allowed. The red line encompasses the possible location of the main and tail rotor of the helicopter when on deck, the Main and Tail Rotor Landing Area (MTRLA). Below this area a maximum obstacle height of 0.11 m is allowed. The black lines encompass the possible location of the main and tail rotor when the helicopter is moving sideways or is hovering above the flight deck. The forward limit is defined by the Main Rotor Flying Clearance (MRFC) and the aft limit is defined by the Tail Rotor Flying Clearance (TRFC). Below the area between these lines, a maximum obstacle height of 0.61 m is allowed.



Area's:
WLA, FFLA:
max. obstacle height 0.01 m
MTRLA:
max. obstacle height 0.11 m
Clearances:
MRFC, TRFC:
max. obstacle height 0.61

Figure 3 Example of a flight deck clearance diagram [Ref. 2]

By combining this diagram with the dimensions of the flight deck and surrounding obstacles, a clear impression of the landing clearance margins is obtained. This can also be very useful when defining flight deck dimensions and obstacle locations for a new class of ship. For an existing class of ship, the compatibility of operations with a new helicopter can be investigated. The correct position of the landing spot can be checked and possible limits on sea state can be established. The size of the diagram is dependant on the sea state as it incorporates the scatter in position of helicopter parts. So if a diagram valid for high sea state is not compatible with dimensions of a certain ship, often a smaller diagram valid for lower sea states will fit. This implies that a limit in sea state can be expected for the flight operations of the helicopter-ship combination under investigation. To construct a flight deck clearance diagram, the HFDCLEAR program [Ref. 4] has been developed at NLR. In this program, the encompassing curves are represented by mathematical expressions, based on statistic flight trials data and on naval regulations. With a particular helicopters' geometrical and statistical data, the program calculates and plots the curves, either on screen (for pre-viewing) or on a plotter or printer. Any helicopter type can be evaluated due to the flexible way of specifying helicopter data.

1.2 Compatibility IAR 330 Puma -Type 22 Batch 2 frigate

It was first checked if the helicopter will fit in the hangar. Comparing the dimensions of the helicopter with folded rotor blades with the internal dimensions of the hangar shows that IAR 330 helicopter will fit in the hangar of a type 22 Batch 2 frigate. Next, the flight deck clearance diagram of the IAR 330 Puma is calculated for several sea states. *Figure 4* plots the diagrams valid for sea state 3 & 4 (green line) and sea state 5 & 6 (red line) over a drawing of the flight deck of the Type 22 frigate. The helicopter reference point is aligned with the circle centre of the landing spot (the centre of the grid). The following is observed from *Figure 4*:

- Sufficient deck length is available between the hangar wall and the Main Rotor Flying clearance (MRFC) up to sea state 6.
- The main landing gear remains clear of the square obstacles behind the landing spot.
- The helicopter tail protrudes aft of the flight deck 5.9 m for sea state 3 & 4 and 6.5 m for sea state 5 & 6. The result is a risk of damage by a stern wave ("rooster tail") strike. The risk will increase with increasing sea state.

The IAR 330 Puma is not equipped with a deck lock system, so it is not dependent on the position of the grid in the flight deck. In order to decrease the length of the tail protruding behind the flight deck, it is possible to define a new landing spot, in front of the current one. The available deck length from the grid centre to the aft wall of the hangar is 16.54 m. Of this length, 2 m should be reserved as working space for the flight deck officer. A new location of the landing spot for the Puma helicopter is obtained by moving the MRFC forward to 2 m from the hangar aft wall. The results are shown in *Figure 5* and are described below:

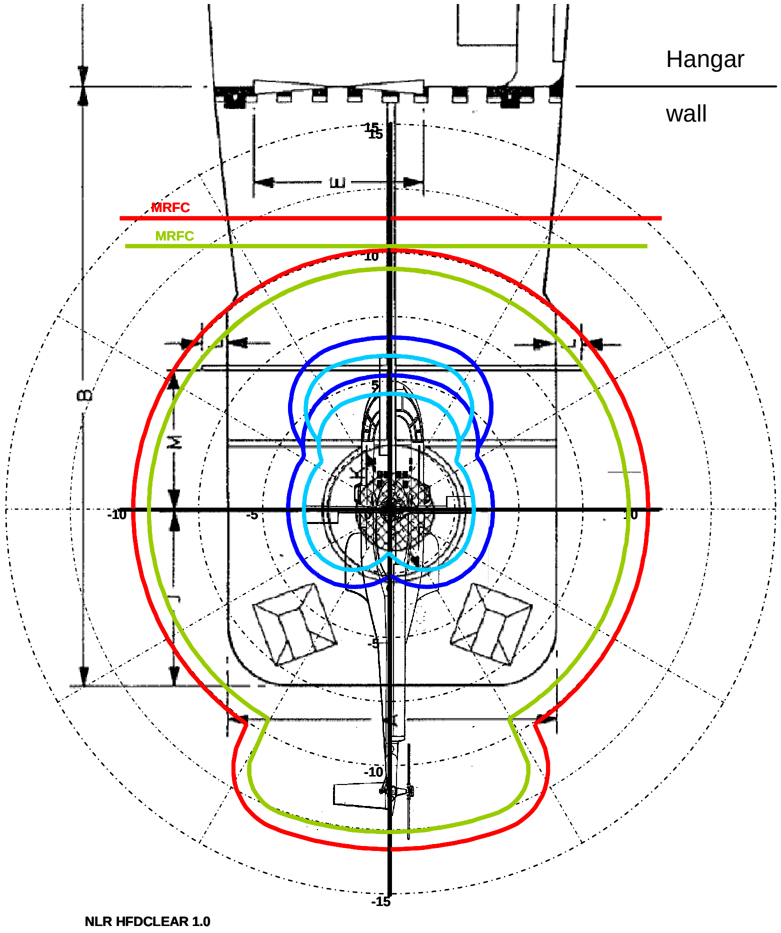


Figure 4 Initial flight deck clearance diagrams of IAR Puma Naval -Type 22 frigate, sea states 3&4 (green line) and 5&6 (red line)

- For operations in sea state 3 & 4 (green line in figure 5), the landing spot can be moved forward 4.3 m. The length of the helicopter tail protruding aft of the flight deck is reduced from 5.9 to 1.6 m.
- For operations in sea state 5 & 6 (red line in figure 5), the landing spot can be moved forward 3.3 m. The length of the helicopter tail protruding aft of the flight deck is reduced from 6.5 to 3.2 m.

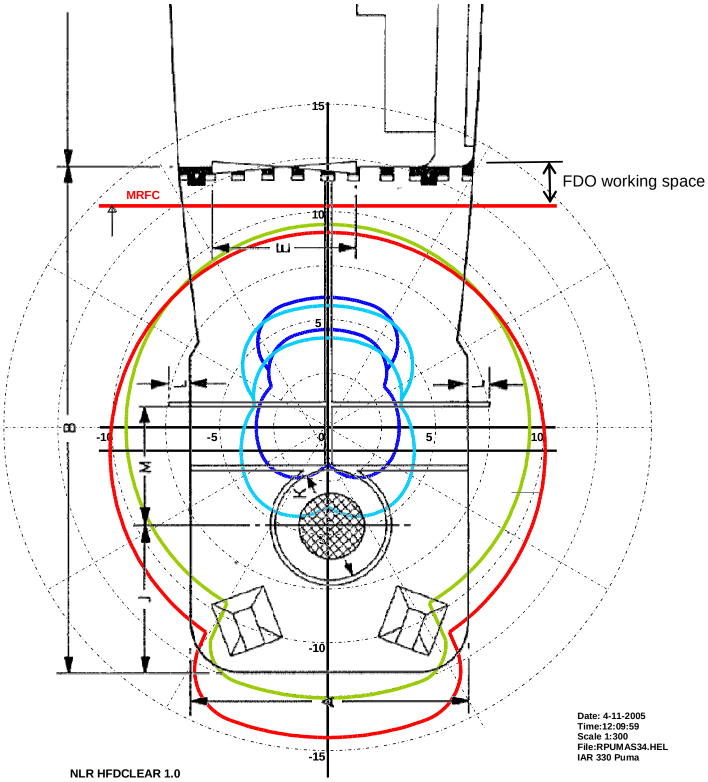


Figure 5 Modified flight deck clearance diagrams when the flight deck landing spot Puma Naval is moved forward over flight deck in order to reduce the tail length protruding aft of the flight deck for the Puma Naval (sea states 3&4 shown by green line, and 5&6 shown by red line)

To avoid the risk of tail damage by a stern wave, the helicopter should be traversed forward immediately after shut down prior to post flight activities (washing, folding etc.).

2. MATHEMATICAL MODELING OF IAR 330 PUMA OPERATING ON BOARD OF TYPE 22 FREGATES

2.1 General model description

Based on previous experiences, a list of general requirements for a generic helicopter simulation tool has been compiled [Ref. 5]:

- It should be possible (and easy) to change the rotor rotational direction so that both clockwise and counterclockwise helicopters can be simulated;
- The tail rotor must work correctly for helicopters with rotors of both rotational direction;
- The centre of gravity of the helicopter should not be used as a reference point for the geometric positions of the different parts of the helicopter, since this prohibits a position change of the centre of gravity during a simulation;
- It should be possible to trim the helicopter completely, without suffering from transient effects of the numerical blade element model;
- An interface with Simulink should be available for controller design;
- It should run in limited time on state-of-art computer hardware (typically less than 1 hour).

As flight dynamics model for helicopter, it was decided to build a non-linear 9-dof model including 6-dof body motion and 3-dof rotor flapping dynamics. In a typical 9-dof model the helicopter body is modeled by dividing it into its main components (rotor, fuselage, tailrotor, horizontal stabilizer, vertical fin) and the rotor includes the dynamic of flapping motion as seen in the non-rotating reference. The following assumptions are made: 1) Aerodynamic forces and moments are calculated using the blade element theory; 2) The tail rotor is modeled as an actuator disc, its dynamic inflow being included in the model in a quasi-steady form by means of a time constant of a value 0.2 sec;; 3) The fuselage, horizontal and vertical tails are modeled with linear aerodynamics; 4) second order rotor disc-tilt dynamics (often the so-called flapping dynamics) are included; 5) The dynamic inflow of main rotor is modeled using a modified Pitt-Peters inflow model which took sideward flight into account 6) wake skew and wake spacing was used to model the wake distortions during hover and maneuvering flight; 7) The rotor is modeled with a centrally flapping hinge and pitch-flap coupling; 8) pre-twist angle is included; 9) the lead-lag motion of the blades is neglected; 10) the blades are rectangular; 11) blade-tip losses are included 12) The fuselage axes are aligned with the frame-station/butt-line/waterline reference 13) gravitational forces are small compared to aerodynamic, inertial and centrifugal forces; 14) the rotor angular velocity is constant and anticlockwise; 15) No reverse flow regions are considered; 16) the flow is incompressible; 17) the blades have a uniform mass distribution; 18) the blade elastic axis, aerodynamic axis, control axis and centre of mass axis coincide.

Initially, the flight dynamics model was implemented as MATLAB-code. Trim runs and time simulations indicated that the use of a numerical algorithm to calculate the aerodynamic forces on the rotor blades makes the code execution extremely time consuming. Therefore, the flight dynamics model including the trim and linearization routines was manually converted to FORTRAN 95. This made the program run approximately 1000 times as fast.

In terms of pilot modeling, it was first chosen to use the so-called SYCOS (Synthesis through Constrained Simulation) pilot model [Refs. 6, 7]. Later, a Simulink model including PID controllers was added to the code. This pilot model can be used in off-line helicopter simulations for evaluation of rotorcraft performance and handling qualities. It overcomes some of the precise, open-loop control of pure inverse simulations, by using a corrective control structure to correct control settings when deviations from the intended flight path are detected. Basically the model starts from the principle of crossover model as shown in 6*a* (the error between the reference flight state yref and the system output is continuously corrected by the pilot in his corrective actions for helicopter stabilisation) but uses the crossover model as part of a pilot. This is done by ensuring that the open-loop transfer function between the error and the output stays the same as in 6*b*. Next, the easiest way to the ensure that the open-loop transfer function between the error and the output stays the same is obtained by adding the inverse of the system plus the output between the crossover element and the system block. This means that the input of the inverse block must be the same as the output of the system, since they cancel each other out. The resulting pilot model is given as in *6c*. Finally, the control structure of the SYCOS pilot model is obtained as in 6*d* and consists of two components placed in series: the first is a crossover element, the output of which is processed by the second part consisting of a learned response that generates the necessary corrective actions. The pilot model uses earth-oriented velocities and heading angle rate of change as input. For helicopters, the crossover frequency and time delay have typical values of 2 rad/s and 0.2 s, respectively.

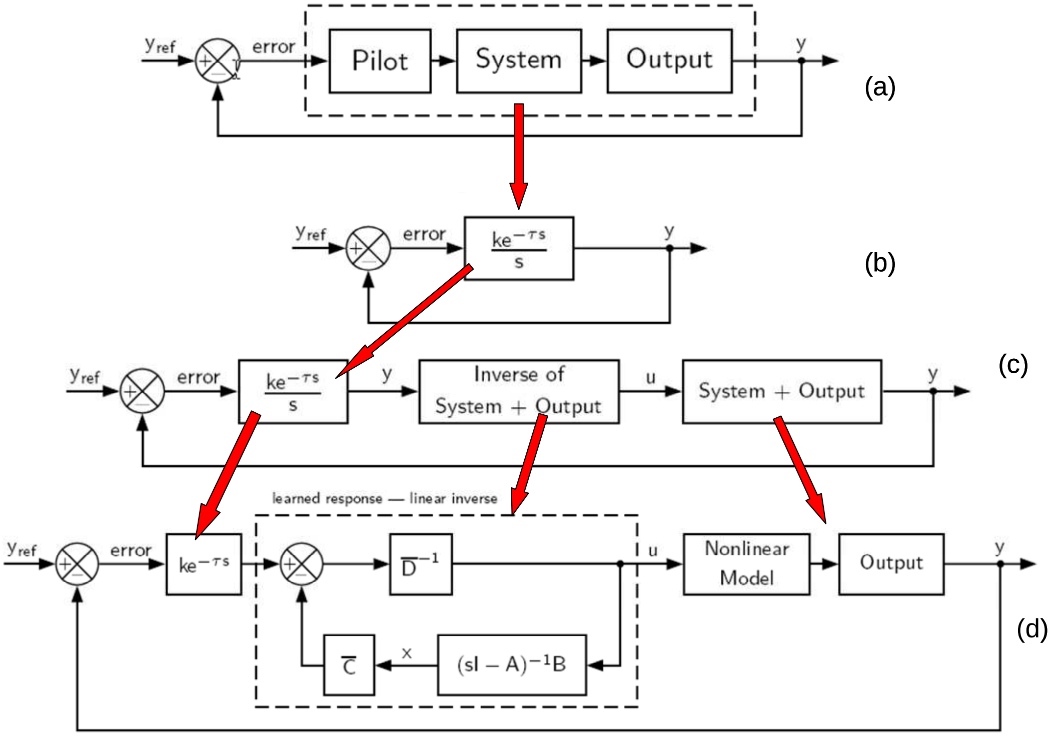


Figure 6 Building the SYCOS pilot structure, showing (from left to right) the crossover component, the learned response or inverse system and the nonlinear model with its output

2.2 Simulating the fore-aft procedure

Generally, for operating in Black sea environment, winds of maximum 20 m/s per direction, a moving platform (roll angles of max. 6.5° and pitch angles of max 3° with a respective motion period of 5.2 s and 2.6 s), and waves heights of maximum 8 m were imposed. The project reviewed the helicopter-ship procedures proposed by reference 2. One of the most common procedures for landing on the ship described in this report is the so-called fore-aft landing procedure. This procedure was chosen as test case for the simulation. A fore/aft landing is performed as follows (see *Figure 7*)

- **Phase I Closure to the ship** to a wait position alongside the ship (preferably to port because of pilots view over the fight deck). The helicopter longitudinal axis is parallel to the ships center-line;
- **Phase II: Lateral repositioning:** fly sideward to the hover position over the landing spot (lateral repositioning maneuver);
- **Phase III: Station Keeping and Landing**: vertically descend and land.

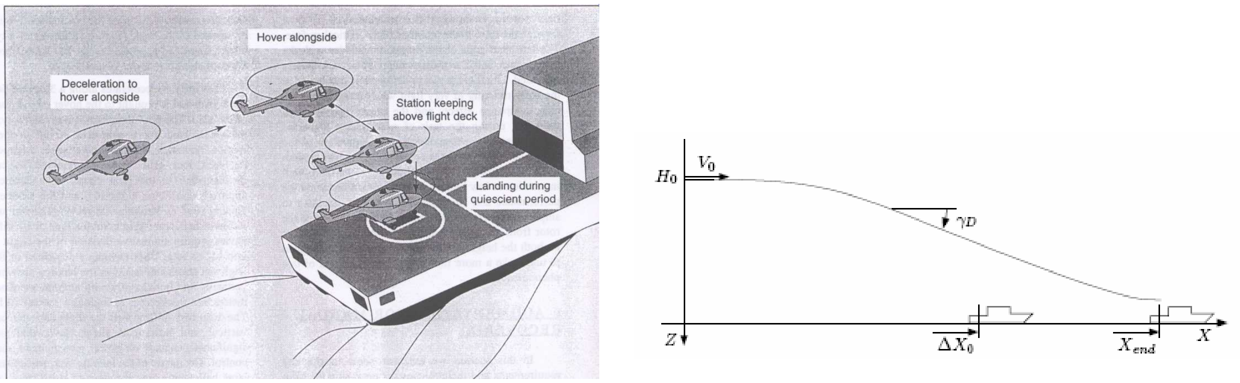


Figure 7 Fore/aft landing procedure and its spatial position [Ref.8]

Figure 8 presents the contour plot obtained when integrating the previously described phases. The ship starts 2300 meters ahead and 30 meters to the right of the helicopter. The initial altitude of the helicopter is 120 meters, and during phase I, it will descent to 20 meters and reduce its speed from an initial 40 m/s to 5 m/s. After that, a lateral repositioning is executed, ending in station keeping above the flight deck of the ship. A descent is initiated, ending in touchdown on the deck with a small vertical velocity. The total simulation takes about 190 seconds. For a detailed description of the mathematical modeling of the controlling during each phase of the procedure the reader is referred to [Ref. 5]. During the simulation, it was observed that the tail rotor control value calculated by the SYCOS linear inverse controller of *Figure 6* was not capable of keeping the heading angle within reasonable limits. Therefore, additional feedback was needed to prevent the heading from diverging from its intended value. An inner-loop corrective control action needed to be added to the controls of the pilot in the form of a PID-controller. Only after the addition of this extra stabilizing loop, the simulation was completed successfully. This shows that, the heading control (or more precisely lack thereof) is one of the prime reasons for piloting instabilities. Other observed instabilities were contained in the values of the pilot time delay and the gain used for the crossover element. These parameters introduced a small delay between the intended velocities and the actual velocities at every time instant. As a result, there was a difference between the actual position of the helicopter and the intended position at the end of the deceleration which needed to be corrected by feeding back the helicopter actual positions and velocities to the subsystem generating the references.

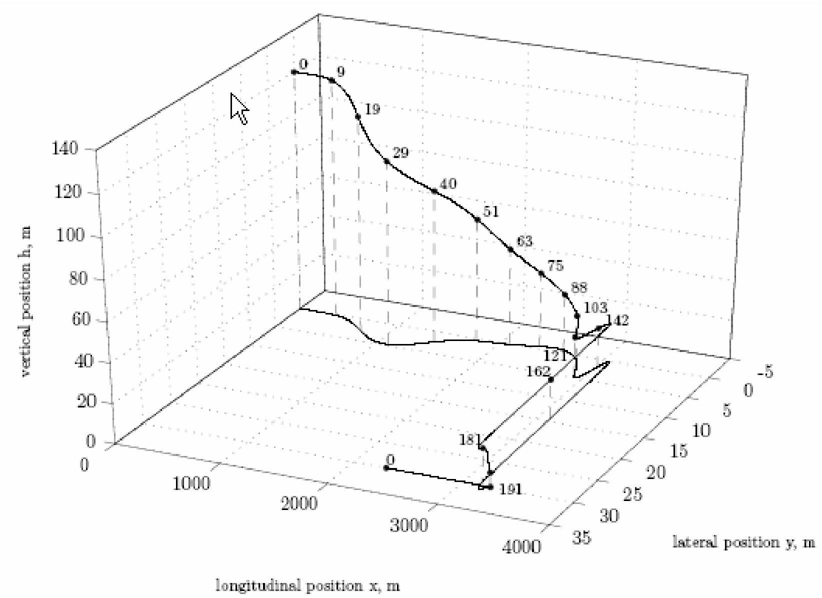


Figure 8. 3-D contour plot of helicopter trajectory in fore-aft landing of an IAR-330 on a Type-22 Frigate

3. CONCLUSIONS

Concluding, the aim of the research described in this paper was to assemble the first steps towards “maritimizing” the IAR 330 Puma helicopter towards Puma Naval for landing on board of Type-22 frigates and determine by means of simulation the critical parameters involved herein. Concerning the physical landing limits of the IAR-Puma helicopter on the flight deck of the Type 22 frigate, it is concluded that:

- The flight deck length of the Type 22 frigate is sufficiently long for operations with the IAR 330 Puma helicopter. The tail of the helicopter protrudes aft of the flight deck.
- The risk of damage to the helicopter tail by stern-wave (“rooster tail”) strikes increases with increasing sea state.
- The risk can be reduced by moving the landing spot forward, since sufficient clearance is available in front of the Puma helicopter, and it is not equipped with a deck lock system. If operations are limited to sea state 3 & 4, the landing spot can be moved forward 4.3 m, reducing the length of the helicopter tail protruding aft of flight deck from 5.9 to 1.6 m. If operations are limited to sea state 5 & 6, the landing spot can be moved forward 3.3 m, reducing the length of the helicopter tail protruding aft of the flight deck from 6.5 to 3.2m.
- To reduce the risk of tail damage by a stern wave, the helicopter should be traversed forwards immediately after shut down prior to post flight activities (washing, folding etc.).

Concerning the model built for pilot-in-the-loop simulation, the results indicated that when flying the fore-aft procedure, the pilot has difficulties in controlling the heading during the deceleration phase to hover alongside the ship. An inner-loop corrective control action in tail rotor collective was added to the controls for stabilizing the simulation. Other critical parameters for flying the fore-aft procedure was the pilot time delay introduced in the crossover element and this behavior points out a PIO-sensitive system.

Generally, the simulation model proved a valuable tool that can be used before performing the expensive and potentially dangerous full-scale testing. The first official flight tests employed during January-May 2007 on board of “Regina Maria” involved low altitude flight and landing on the flight deck (see *Figure 9*) By that time the Puma was equipped with a harpoon deck lock system. The first pilot comments were that Puma Naval behaved “*extraordinarily, being like a dragon pulled down to the deck by its new harpoon*” [Ref. 9].

Figure 9 Puma Naval testing in Black sea area, May 2007

REFERENCES

[1] Radnef, Sorin, “Dinamica si controlul elicopterului in fazele terminale marine”, internal report, INCAS, 2005, in Romanian

[2] R. Fang, Cdr. (Ret.) H. W. Krijns, R. S. Finch, “*Helicopter/Ship Qualification Testing*”, AGARDograph RTO-AG-300 Vol. 22 AC/323(SCI-038)TP/53

[3] R. Fang, P.J.A. Booij, “*Helicopter-Ship qualification testing, The Dutch clearance process*”, Presented at the American Helicopter Society 62nd Annual Forum, Phoenix, Arizona, May 9-11 2006

[4] W.P.J.Visser, “HFDCLEAR, A program for calculation of clearances on helicopter flight decks”, NLR memorandum VH-95-006, Oct. 1995

[5] Van Hoydonck, Wim, Pavel, Marilena D., “*Investigation on the simulation and handling qualities for helicopters operating near ship decks*”, AIAA Modeling and Simulation Technologies Conference”, 15-18 August 2006, Denver, Colorado, AIAA 2006-6810

[6] Bradley, R., & Brindley, G., “Progress in the Development of a Robust Pilot Model for the Evaluation of Rotorcraft Performance, Control Strategy and Pilot Workload”, 28th European Rotorcraft Forum, Sept 2002, Bristol, UK.

[7] Bradley, R., & Thomson, D. G., “*Helicopter and Tilt-Rotor Inverse Simulation Methods, Features, Problems and Cures*”, 31st European Rotorcraft Forum, Florence, Italy, Sept. 2005

[8] Lumsden, R. B., Wilkinson, C. H., and Padfield, G. D., “*Challenges at the Helicopter-Ship Dynamic Interface,*" 24th European Rotorcraft Forum, Marseilles, France, Sept. 1998

[9] “Evenimentul Zilei” magazine, 31 Jan. 2007, in Romanian