EIGHTEENTH EUROPEAN ROTORCRAFT FORUM

D - 12

Paper N°.45

THE SUPER PUMA HELICOPTER SIMULATOR
OR, "HOW TO MEET THE MOST DEMANDING REQUIREMENTS OF THE EARLY 90's"

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September 15-18, 1992

AVIGNON, FRANCE

ASSOCIATION AERONAUTIQUE ET ASTRONAUTIQUE DE FRANCE

THE SUPER PUMA HELICOPTER SIMULATOR
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1. INTRODUCTION

Operators are exploiting the exceptional potential of helicopters and are devoting more and more tasks to the machine, often at the limits of the operational conditions.

Some of the various roles devoted to helicopters are particularly demanding in term of training accuracy as incorrect or unrealistic training may have fatal consequences during real flight.

A simulator allows crews to be safely trained in risk conditions which would not be possible utilising the actual helicopter. Nevertheless some of the various roles devoted to the helicopters, such as ground support, search and rescue (SAR) and attack missions are particularly challenging to the simulator industry.

Support role and attack missions usually require Nap Of the Earth (NOE) flight. This involves flying below the height of trees, sometimes with a ground clearance as low as one metre, and flying under high voltage power lines. It involves high manoeuvre rates and the use of ground terrain, buildings and vegetation for concealment. Landing and taking off from obstructed areas, or from shipdecks in case of maritime missions during night flight, or in bad weather conditions are often potential dangers to be added to an already hostile environment.

SAR missions are also particularly demanding for the crews as the control of the helicopter in mountainous areas or at sea in storm conditions is not an easy task.

2. ROLE LIMITATIONS WITH CURRENT HELICOPTER SIMULATORS

Simulators have already been widely used for extensive helicopter training in cockpit familiarisation and manipulation procedures, general flight training, IFR training, and system malfunction and emergency procedures. In fact, this type of training only covers a part of the full mission performed by helicopters, and helicopter simulators have seldom played a leading role in such full mission training.

Due to limitations in the fidelity of simulators, the most demanding part of the training is still carried out using the actual helicopter.

The limitations of simulators are usually expressed in terms of:

- limited visual field of view compared with the actual aircraft,
- inadequate detail in the simulated visual environment,
- lack of fidelity of simulated helicopter behaviour near the ground and during transient phases.

In theory, the technology was available to address all these deficiencies but, in practice, the complexity and resulting expense was not deemed to be cost effective.

3. THE STUDY OF OPERATIONAL MISSIONS OF SUPER PUMA HELICOPTERS

The PUMA/SUPER PUMA helicopters cover a wide variety of operational missions, from transport to tactical support, from SAR to maritime roles, in all conceivable environmental conditions.

As such, the SUPER PUMA was considered an ideal candidate for an in-depth study of such missions.

The objectives of the study were four-fold:

1) identify those elements essential for piloting the helicopter,
2) prioritize the importance of these elements,
3) relate these elements to current or future simulator technology,
4) define a simulator able to provide this operational training at reasonable cost.

3.1 Flight Trials

The helicopter missions during these flights covered one or more typical flight regimes:

- IFR flights,
- low level flights,
- NOE flights,
- formation flights,
- flight in mountainous areas,
- flights over water,
- night flights with and without NVG,
- landing and take-off in various situations:
  - urban platforms,
  - obstructed natural areas,
  - hill-tops and sloping areas.

Analysis of flight recordings was made at the end of each flight by a team including helicopter pilots and THOMSON-CSF engineers.

3.2 The Main Lessons

Among the results of the analysis, two major points were brought out:

1) the instinctive use by the crew of a wide range of varied visual elements as piloting references,
2) the basic role of the lower cockpit field of view as a source of visual information.

From discussions held with the different crews it was apparent that during missions requiring a heavy workload for the pilot, particularly during low level flight or hovering in hazardous conditions, the pilot was flying by instinct without reference to cockpit instrumentation.

Thus, during these flight phases the fidelity of the simulator must be such that it has no diverting effect on the concentration of the crew.

1) Importance of the content of the visual information

Horizontal and vertical distances are mostly estimated by the pilot using typical visual references such as roads, posts, houses, trees, etc., but smaller details such as windows, fences, etc., are also used. The chosen element is subconsciously compared to similar references recorded from experience. The precision of the estimation may be as good as around 10 cm.

Closure with the ground or obstacles is detected through progressive appearance of numerous details all around the helicopter. As the precision of this detail increases, the pilot instinctively reacts by controlling the helicopter speed, attitude and altitude.

Ground speed is estimated from relative motion between background and foreground vertical elements and from "ground rush".

Attitude of the helicopter is estimated by visually comparing the horizon line with the rotor disc attitude and cockpit frame structure.

Hence at low altitude, most information required by the pilot for handling the helicopter is of a visual nature, provided that motion cues are well coordinated with the visual cues.

2) Importance of field of view

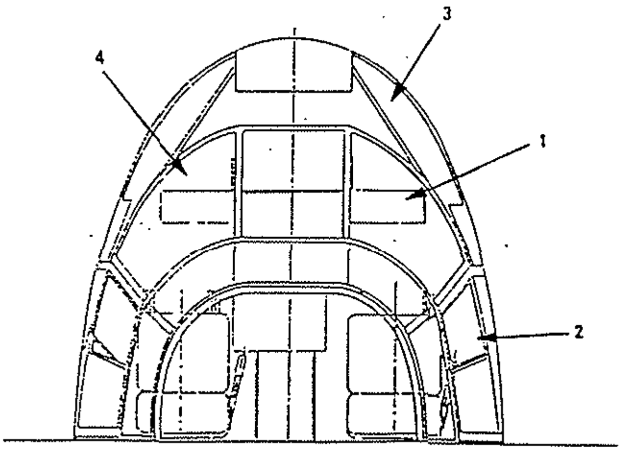
The visibility diagram of a PUMA/SUPER PUMA type cockpit has been divided into four distinct zones. All zones are referenced from the pilot position.

Zone 1 represents the central field of view around the theoretical position of the pilot eye (± 30°H, ± 30°V). This zone corresponds to the front window and half of the central window of the helicopter.

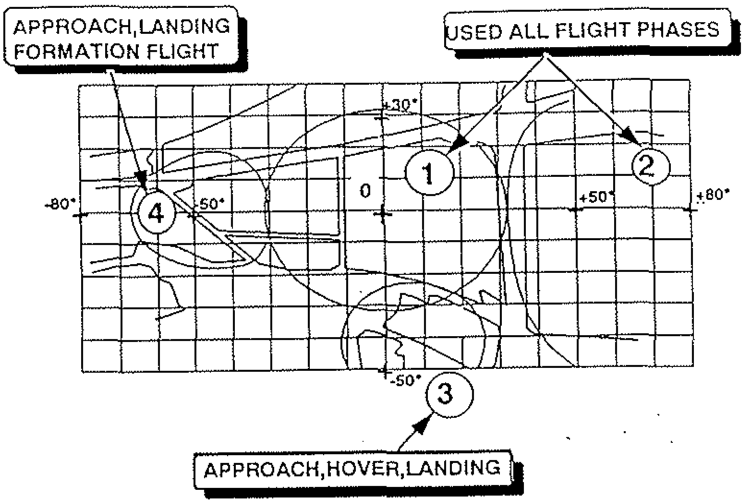
Zone 2 represents the side field of view (from 30° to more than 90°H, and from 25° to - 55°V). This zone corresponds to the pilot door windows.

Zone 3 represents the low field of view (from 30° to - 10°H, and from - 20° to - 60°V). This zone corresponds to the cockpit chin windows.

Zone 4 represents the cross cockpit side field of view (from - 30° to - 70°H, ± 25°V). This zone corresponds to the opposite front window and half of the central window.



PUMA/SUPER PUMA helicopter
Pilot visibility diagram partition



PUMA/SUPER PUMA Helicopter
Windows and visibility diagram correspondence

Zones 1 and 2 are used by the pilots during all flight phases. The visual information collected, such as obstacles, allow the pilot to plan the future flight path.

Zone 3 is used during approach, landing phases and during hovering near the ground. The visual information collected provides height and position evaluation. The information provides immediate feedback to the pilot.

Zone 4 provides additional information during landing phase and during formation flight. The visual information collected are used for position evaluation.

Even if used only during a short part of the total mission duration, the field of view covered by zone 3 is absolutely essential for the pilot to manage the most critical flight phases. The results from the above analysis indicate that a continuous 160°H x 90°V field of view is a minimum requirement in order to satisfy all the PUMA/SUPER PUMA mission training needs.

4. VISUAL DISPLAY SYSTEM

During Nap Of the Earth flight, low speed flight, shipdeck landing, etc., the main sources of information needed for the SUPER PUMA pilot to achieve his mission are visual and motion cues.

4.1 The Field of View

In large aircraft simulators a limited Field Of View (FOV) is usually acceptable because it is a cost effective solution and because the reduced FOV does not really degrade the training efficiency. In military aircraft simulators a better visual simulation is preferred, even if necessary at the expense of motion cues fidelity.

For the SUPER PUMA simulator, no trade-off is possible between FOV, resolution, level of detail and motion cues since the crew needs the maximum possible information. The vertical field of view has to be greater than 60° vertical and if possible up to 100° to cover the complete lateral windows and chin windows. Due to the limitations of the canopy, the horizontal FOV can be limited to between 180° and 220°.

4.2 New display system

Coverage of such a large FOV with a continuous visual scene can be achieved using a number of video projectors and a large spherical screen. However, the implementation poses two problems:

1) Helicopter piloting uses both visual and motion cues. The use of a fixed display screen and a cockpit on a motion platform generally induces motion sickness due to lack of correlation between motion and visual systems. The most efficient solution consists of using a motion-compatible visual display system. Such a system provides simultaneous high visual and motion performance. The standard motion platform is the 6 degrees of freedom synergistic motion system. To avoid high development costs, the cost effective solution is to use this standard motion platform. Limitations in mass and inertia capacity of this kind of platform lead to a need to minimize the weight of each element, especially for the screen and for the projectors which are far from the motion centroid,

2) Due to mass reduction and to cost considerations, the number of projectors has to be minimized with respect of the requirements for large FOV and image quality. Since the best image quality is required in terms of resolution, brightness, contrast and edge matching, the best and only way is to use a high brightness, high resolution projector. A few years ago it was difficult to reduce the number of projectors due to:

   - limited resolution of video projectors,
   - capacity of the CGI limited to one Mpixel per channel.

   Now the one Mpixel limitation barrier has been exceeded and high definition TV projectors have been developed, able to project up to 2,000 lines of 2,000 dots in 40 milliseconds. To achieve the goal of a motion-compatible visual system with large FOV and high resolution image, THOMSON-CSF has developed a low weight, high stiffness spherical screen able to cover FOV as large as 200° Horizontal x 100° Vertical. The horizontal FOV can be increased by adding segments of spherical screen. The vertical FOV can also be increased by adding new elements manufactured with the same set of tools. For the European project "EUREKA" and for various simulation applications, THOMSON-CSF has also developed a new version of its CRT projector called PHEBUS 5. PHEBUS 5 is a raster calligraphic, 9" CRT projector, with HDTV capability. This projector is manufactured in several modules to facilitate layout of the elements on the motion platform and to reduce payload inertia.

4.3 The Spherical Screen

The spherical screen is one of the main sources of mass and inertia. Its diameter cannot be smaller than 7.4 m to take into account the volume of the side-by-side crew seats for the helicopter cockpit, and relative position between screen, projector and observers. The only solution to reduce inertia and mass was to manufacture the spherical screen in a material as light as possible. The following design considerations have been taken into account to develop the screen:

- image quality: surface accuracy, joint distortion, screen dynamics,
- system characteristics: mass and inertia, light tightness, cost,
- manufacture long term stability, transportability, gap filling, structural integrity.

With these design considerations the following decisions have been taken to choose the most efficient material and the best design:

Decision	Discard	Choose	To achieve
basic division of active screen	5 or less segments	8 segments	size for manufacture and transport
basic material	metal	composite	size, accuracy and stability
basic construction	thin skins and ribs	core/ sandwich	local accuracy
core type	balsa or foam	honeycomb	stability and accuracy
honeycomb	aluminium or Kevlar or carbon	Nomex	weight and cost
resin type	polyester	epoxy	long term stability
skin fibre material	Kevlar, glass	carbon	stiffness and weight
skin fibre type	woven or chopped strand	unidirectional	stiffness and weight
joints	metallic edges	integral flanges	joint accuracy and integrity

The results of these decisions have been the choice of a sandwich composite material made of 2 skins of prepreg carbon fibres with a Nomex core. Such a material has a mass of 4.4 kg/m^2. A static and dynamic analysis using a finite element model has been conducted both for the screen alone and for the complete system (motion platform, screen, instructor compartment, projector support, etc.).

The stress in the material is a few % of the elastic strength and the first resonant frequency for the complete spherical screen on the motion platform is higher than 20 Hz, which exceeds the rotor frequencies of the simulated helicopter. This theoretical frequency has been confirmed by dynamic testing after installation of the screen on the motion platform. To obtain the required quality for the screen, the tools manufacturing, the process and the inspection method have been chosen and developed in conjunction with specialists in this field. All the sections are moulded on carbon tools and cured in an autoclave. The choice of the material for tools and sections coupled with the autoclave process avoids expansion problems and guarantees the accuracy of each element.

4.4 The Projector

Since the mass is critical on the motion platform, the image quality must be obtained by a minimum number of projectors. The only solution consists in the use of a high performance projector. The required resolution for such a projector can only be guaranteed by CRT projectors. The following considerations have been taken into account during development of the PHEBUS 5 projector:

- image quality:	resolution, brightness, contrast, edge matching,
- system characteristics:	mass and inertia, life cycle cost, small size, vibration resistance,
- manufacture:	modularity, maintainability, adjustments.

According to these considerations, the following decisions have been taken to achieve the best design:

Decision	Discard	Choose	To achieve
CRT size	7 inches	9 inches	brightness and resolution
CRT focus		electro-static or electro-magnetic	modularity (cost versus higher resolution)
Lens type	glass	hybrid (multicoated glass: plastic	cost and weight
Lens coupling		air liquid	contrast
Deflection	raster only	raster/ calligraphic	light point quality
Geometry and brightness control	analog	fully digital	ease of adjustment, image quality
Edge matching	4 sides analog	4 sides fully digital	edge matching quality
Mechanical concept	one piece projector	separate projection head and deflection amplifiers	ease of installation and mass distribution

The projector developed from this design study is the first HDTV projector. It is used for industrial HDTV applications, on civilian aircraft simulators with the LINK-MILES AWARDS display system and for display systems on military aircraft and helicopter simulators. The high brightness and unique capacity of PHEBUS 5 to display up to 4 Mpixels in 40 ms enable a large FOV to be covered with a small number of projectors. For instance, with a 2 Mpixels per channel CGI a FOV of 60° Vertical and 200° Horizontal can be covered by only 4 projectors with a resolution of 2.4 arc minute per pixel and an imperceptible join between two adjacent channels.

4.5 Conclusion

THOMSON-CSF offers an off-the-shelf motion-compatible visual system which allows high motion and visual performances. This visual system includes a lightweight, high stiffness spherical sceen using aerospace technology and invisible edgematched state-of-the-art HDTV projectors.

5. VISUAL ENVIRONMENT

In addition to a high quality display system covering a wide field of view, the visual system of the SUPER PUMA flight simulator needs a highly detailed and very realistic representation of the visual environment.

This can be achieved through a close understanding of which visual cues are most important in the SUPER PUMA real visual environment, together with the choice of a powerful image generator taking full advantage of the most advanced modelling techniques such as high detail terrain modelling and extensive photographic texturing with microtextures.

5.1 Major Visual Cues

The SUPER PUMA study conducted by THOMSON-CSF led to a classification of the methods and visual references that are mostly used by the pilot for intuitive evaluation of distance, speed and attitude flight parameters in operational conditions.

The following is a summary of this classification.

1) Distance evaluation

The main estimation methods used for evaluating horizontal proximity and vertical height above terrain appear to be:

- landmark identification,
- scale comparison,
- dimension evaluation.

The most important visual references are:

- vegetation (trees, bushes, etc.),
- buildings,
- small objects (rocks, stones, etc.),
- other helicopters (formation flying).

Thus, the visual environment should include a great number of objects, with a highly realistic representation close to the helicopter to allow accurate distance estimation to within 10 cm.

2) Speed evaluation

The main estimation methods used for evaluating horizontal and vertical speed, including slow relative movements, are based on:

- ground rush,
- dynamic parallaxes,
- convergence/divergence of ground elements.

The most important visual references for speed evaluation appear to be basically the same as for distance evaluation.

This requires that a realistic representation of those visual references should be available at both close and far range.

3) Attitude evaluation

This concerns the pitch, roll and orientation of the SUPER PUMA. The main estimation methods used for evaluating such parameters are based on:

- horizontal and vertical planes,
- parallax (with background),
- angular references.

The visual references most needed for attitude evaluation are all the elements of the environment that may be considered to be a point or a set of points:

- colour spots (vegetation, terrain),
- isolated trees,
- relief bumps,
- small objects (rocks, stones, etc.),
- other helicopters (formation flying),
- imaginary planes formed by reference points,
- horizon planes.

5.2 VISA Image Generation Power

A lot of visual references with adequate realism means a lot of image generation power with an adequate use of that power.

Among the new features of VISA, the real-time Computed Image Generator (CIG) developed by THOMSON-CSF, are key power optimisations that allow the SUPER PUMA simulator to benefit from state-of-the-art image generation technology at reasonable cost:

- advanced load management including the generalization of levels-of-detail handling (terrain, objects, textures), thus taking best advantage of the whole CIG power available at any moment according to the effective scene viewed by the crew, and allowing very high detailed representation in the foreground,
- Multiple Sorting Algorithms (MSA): a mixed approach to Hidden Parts Removal (HPR) that saves rendering power without constraining the database contents,
- large full colour texture capacity in memory, refreshable from disk, to dramatically increase environment details by simply using higher photographic resolution,
- high computing precision at every stage of the process, so to put as much information in every pixel as it contains in real images.

1) High Detail Terrain Modelling

The increase of the CIG power allows higher density terrain representation (including features and fixed objects), but traditional DataBase Generation Systems (DBGS) mostly use automatic transformation of DMA elevation and cultural data, together with manual enhancement of highly detailed areas directly modelled at polygon level.

This approach may be satisfactory for medium and high altitude helicopter flight, but the manual enhancement part becomes very costly when it comes to low altitude NOE applications, as well as for ground applications.

The amount of details on the ground can be easily increased by using specific phototextures deduced from aerial photographs, but the 3D information which is so important for tactical helicopter flying still comes from elevation files and from 3D objects modelled and placed by hand.

The High Detail Terrain Modelling concept that allows cost effective generation of highly detailed large areas is based on:

- an easy modelling of precise terrain elevation and cultural features, along with phototextures, using simplified modelling techniques compared to the use of polygons,
- a powerful off-line automatic transformation process which develops and integrates the source elements into a complete and consistent polygon representation, with such advanced features as:
    - generation of complex infrastructures (roads and rivers with real 3D profiles, crossroads, bridges, etc.) properly integrated in surrounding terrain,
    - realistic placement of numerous small elements (vegetation, rocks, poles, etc.) according to the nature of the surrounding terrain elements,
    - generation of correlated levels of detail, according to the operational use of each type of element (distance, speed or attitude evaluation, tactical elements, etc.),
- most complex objects or special areas may still be modelled or modified by hand to allow unique representations or special effects.

This approach results from previous experience in database modelling for both ground and helicopter applications, where highly detailed representations could no longer be restricted to small areas, and is compatible with Project 2851 source data.

2) Extensive Photographic Texturing With Microtextures

The increased CIG texture capacity allows the use of phototextures to be dramatically extended to both geo-typical and geo-specific coverage of the gaming area, varying from low level terrain detail to far environment views at high altitude.

Texture rendering in tactical areas and landing zones for the SUPER PUMA requires both a geo-specific photographic representation and a very high resolution. Since very high resolution (less than 20 cm) aerial photographs may not be available or would need unreasonable texture capacity in the image generator, the right choice is to extend the resolution of the specific phototexture by a microtexture modulation computed in real time.

Modulation allows the simultaneous display, on the same polygon, of two textures with different resolutions. This makes possible to combine the realistic data of the specific phototexture with the high resolution data of the microtexture which is generic, typical of a ground nature, and can also be deduced from a photograph.

The pilot's eye gets naturally and steadily acquainted with the dominant texture detail in the scene, ranging from the low altitude approach where specific photographic elements (paths, bushes, etc.) are used as visual markings, up to the "touch down" where the microtexture details (grass, stones, etc.) allow the pilot to keep evaluating altitude, speed and attitude.

6. FLIGHT MODELLING

6.1 Operational Requirements

A full mission simulator will cover a wide range of flight conditions throughout the flight envelope, from take-off, hover, transition to forward flight, sideward flight, backward flight, landing, flight in and out of ground effect, autorotation, vortex state, etc. Moreover, simulation is possible outside of the normal flight envelope with sufficient realism.

For the SUPER PUMA simulator, the stress is put on the NOE flight with low speed and low height conditions in order to achieve tactical missions, using terrain features to avoid potential threats.

In the tactical use of the helicopter, special tasks have to be included, as extension to the general flight features, such as:

- shipdeck landing with varying sea states,
- sling load transportation,

- winching operations.

All these tasks involve low speed, low height flight with a high workload for the pilot.

6.2 Mathematical Model Requirements

1) Flight conditions

Due to the extent of flight conditions, the helicopter flight model has to face highly non-linear effects in comparison to a fixed wing aircraft model. The different parameters which have an effect on the helicopter behaviour are:

- helicopter linear speed vector,
- helicopter rotation vector,
- rotor rotation vector,
- flight controls.

Moreover, as the helicopter is composed of the body and an articulated rotor, inertial forces act on the motion of the rotor and consequently on the rotor forces and moments.

A solution using coefficient modelling techniques is not satisfactory when considering non-linearities, helicopter aerodynamics complexity and unsteady flight conditions. The best way is to consider the helicopter as several parts:

- main rotor,
- tail rotor,
- fuselage,
- horizontal tail plane,
- vertical tail plane.

These individual parts are faithfully modelled, taking into account the main rotor wake interaction on each other part.

The main rotor model is a Blade Element Theory (BET) model which assures the correct level of simulation for non-linear and dynamic characteristics.

2) High workload tasks

To ensure good training during high workload tasks and accurate man-in-the-loop simulation, it is necessary to provide sufficient fidelity in the flight handling modelling. As for the flight conditions, the BET model gives faithful transient cues using a high computing iteration rate necessary to represent the main rotor dynamics.

6.3 BET Model

1) Model capabilities

Compared to classical models, the BET model has the following features:

- each blade is modelled separately as a number of elements, taking into account: variable profile and blade twist,
- local phenomenons on the rotor disk are computed, such as ground effect on induced velocity, "blade advance/retreat" phenomenon, blade stall, induced velocity distribution, flapping and lagging motion of the blades,
- local malfunctions acting on the blades such as icing, projectile impacts, dissymetric blades, rotor out of track are taken into account,
- iteration of the program, rather than averaged out over one complete rotation, allows vibration due to rotor rotation to be calculated in real time,
- compared to the traditional analytical integration method, the numerical method does not require simplifications.

2) BET model overview

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BLADE ELEMENT MODEL COMPUTATIONS:

    Induced inflow at the centre of the rotor hub.

    Air velocity at the centre of the rotor hub.

    Acceleration at the centre of the rotor hub.

      ┌──► Blade loop
      │          Axis transformations for the blade .
      │          Blade angular velocities.
      │          Blade acceleration forces.
      │          Lag damper and hinge.
      │          Flight control angle on the blade.
      │          Blade hinge local air velocity.
  X 4 │          Induced inflow direction vector in blade axes.
      │
      │   ┌──► Blade element loop.
      │ X 5│           Induced inflow distribution on the element.
      │   │           Blade element aerodynamics.
      │   └──  End blade element loop.
      │
      │          Blade equations of motion
      │          Computations of flapping and lead-lag angle for the blade.
      └──── End blade loop.

    Sum the rotor forces and moments in helicopter axes.
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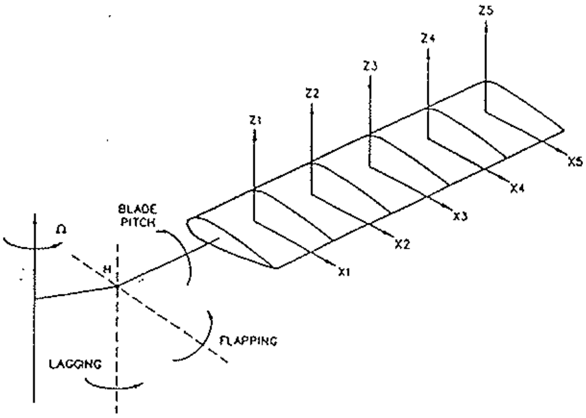
FIGURE 1
BET computation



Where :

H is the hinge
Z_i is the lift of element i
X_i is the drag of element i
Ω is the rotor speed

FIGURE 2
Breakdown of a blade

3) Induced velocity

The BET model needs an effective computation of the induced velocity because the induced velocity drives the model performances. Off line, a theoretical induced velocity model computes the corresponding data in the whole flight envelope, including autorotation and vortex state.

6.4 Performance

As the integration method is a numerical one, it needs large computation power to compute elementary parameters for each blade element and for each blade. The resulting quality depends on the number of elements per blade and the number of computations per rotor rotation in order to have a correct representation of rotor forces and moments through the rotor disk.

It is considered that at least 5 elements per blade and 30 computations per rotor rotation (i.e. 12° azimuth step) are required to obtain satisfactory results. For the SUPER PUMA with a nominal rotation rate of 265 rpm a computation step for 4 blades and 5 elements by blade will have to take less than 7.5 ms to achieve real-time simulation.

The necessary computing power is obtained by using a specialised microprocessor board (MERCURY MC860 with INTEL i860 chip). The type of BET model computations is well suited to the processor for matrix and iterative loops.

A computation step is achieved in 3 ms on this processor.

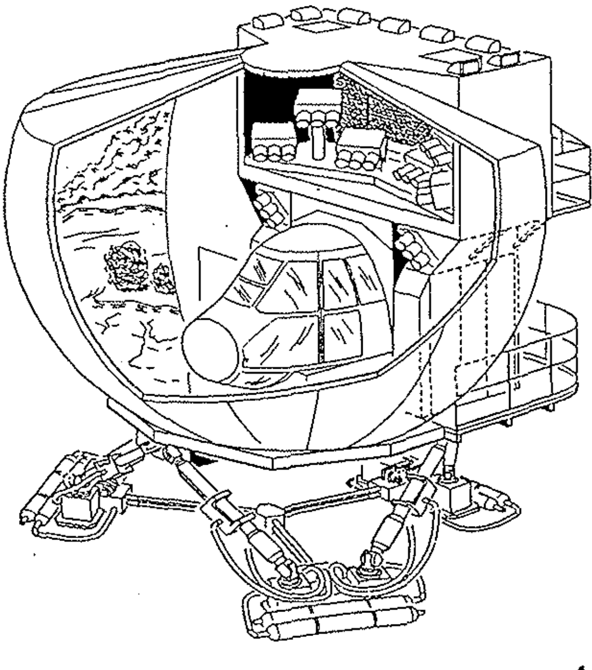
7. THE AS332 SUPER PUMA SIMULATOR - A REALITY

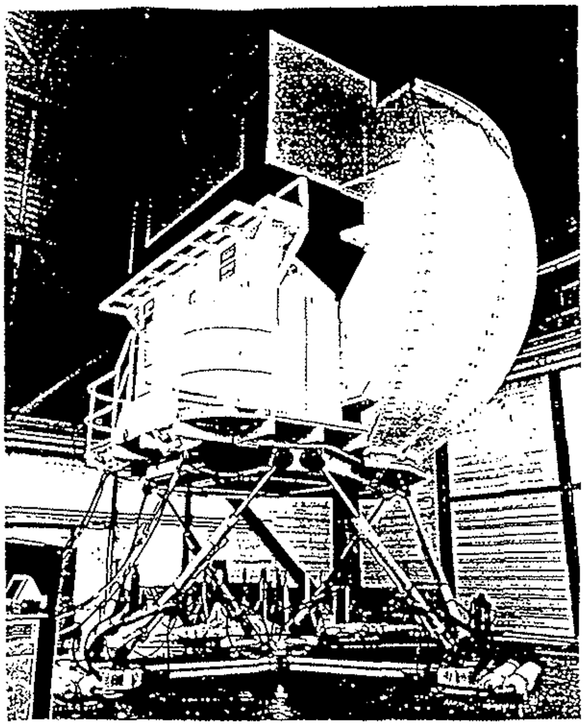
THOMSON-CSF is presently manufacturing an AS332 SUPER PUMA full mission simulator derived from these concepts.

The simulator is specifically designed to provide tactical flight training including NOE flight training in a realistic European type environment.

Simulator design has taken into account the results of the above-mentioned study and in particular, it includes the following noteworthy features:

- a large visual FOV using an on-board carbon fibre screen to provide up to 200°H x 100°V. Although this full FOV capability is not being utilised currently, there is the capability for a future upgrade to add more projectors and CIG channels without substantial modification to the simulator configuration,
- a visual gaming area, digitized from the real world terrain, including highly detailed tactical zones. These zones in database are characteristic either of hill areas with gorges and narrow valleys, forested, HV power lines and natural obstacles, or of urban and suburban areas. Photographic textures have been used to provide high fidelity representation of a real landscape,
- high fidelity helicopter handling simulation. The use of a blade element rotor model provides an accurate simulation of handling for ground effect, small control inputs, transition and dynamic flight regimes.





Helicopter Simulator AS332 SUPER PUMA

8. CONCLUSION

The on-board motion-mounted spherical screen combined with high resolution projectors display system developed by THOMSON-CSF is a technical and cost effectiveness solution to large visual field of view requirements.

The use of Blade Element Theory (BET) techniques for modelling main rotor thrust plus the use of a sophisticated aero model integrated with realistic flight control, motion, vibration and visual cues provides the necessary simulation environment for effective training transfer. The validity of the aero handling is validated by reference to aircraft flight trials.

The combination of a large visual field of view, high detail visual images and realistic simulated helicopter behaviour near the ground allow the helicopter simulators, such as the AS332 SUPER PUMA simulator, to be able to cope with the NOE flight and attack mission training challenge.

ABOUT THE AUTHORS

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