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EXPERT SYSTEM BASED ON CASE-BASED REASONING APPROACH FOR ANALYSIS AND SIMULATION OF H-V TESTS

by

M. Bonetti,
Flight Test Engineering
Agusta, Italy

S. Bandini
Dipartimento di Informatica
Sistemistica e Comunicazione
Università Milano-Bicocca

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1 Abstract

The flight trials required to establish the H-V limitations are very critical; a system able to simulate and predict the aircraft performance with adequate accuracy may reduce the number of flight tests required, increasing flight safety too.

In order to approach this problem from a different point of view, the possibility to apply Artificial Intelligence has been studied to improve the results obtained by traditional methods (analytical method and direct simulation).

This paper presents the research activity carried out to exploit the opportunity coming from this techniques to treat data on the analysis of H-V flight test results, in order to implement a flight simulator for this kind of manoeuvre.

These approach permits to build a model of the knowledge the pilot use to carry out the manoeuvre, describing the system pilot-helicopter in terms of *conditions* that determine a *piloting action* that cause an *effect* on the helicopter behaviour.

The inference engine extracts the knowledge from a dedicated Data Base by a retrieval algorithm that returns the case closer to the flight condition gave in input (identified by GW, ambient conditions and control movements).

The knowledge base of the Expert System[1] is described as for the method followed to select the data as for the information stored in the data base.

The preliminary results obtained by running the program are presented and discussed.

Knowledge management aspect come from the CBR treatment of the information are highlighted and discussed too.

[1] ES are programs for reconstructing the expertise and reasoning capabilities of qualified specialist within limited domain reasoning [1].

2 Nomenclature

AGL	Above Ground Level
AI	Artificial Intelligence
CBR	Case-Based Reasoning
DB	Data Base
ES	Expert System
GW	Gross Weight
H-V	Height Velocity
KB	Knowledge Base
KM	Knowledge Management
RA	Retrieval Algorithm

3 Introduction

H-V limitations are determined by a set of flight tests. At a datum altitude and weight the trials starts at combination of height AGL and speeds that are certainly safe condition, then the testing go on changing the conditions, step by step, up to the boarder of the dangerous area, as Figure 1 shows.

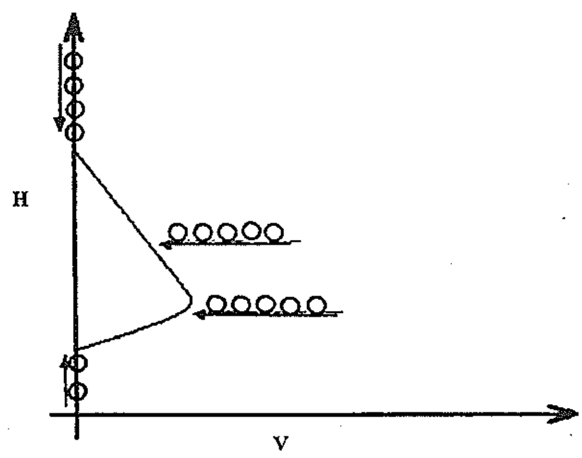

Figure 1 - H-V testing sequence

During these trials, the test pilot use both his own general experience in fly and particular experience on the helicopter tested in order to perform a safe landing, stressing the test condition up to the maximum limit of power available, minimum rotor RPM and vertical speed at touch down are reached, establishing the best performance.

After every single test point carried out the pilot learn something more about the behaviour of the aircraft (i.e. his capability growths) and he is able to estimate the performance margin (in terms of weight, height or speed) to decide the next condition to test with safety.

This process could be defined as an incremental learning, and there are a lot of AI techniques to realise agents[2] that are able to perform *incremental learning.*

The experience the pilot acquire and the reasoning that he perform is explainable by words of natural language relative to clearly measurable variables (as "in the previous condition I landed with very low vertical speed: increase the weight by 50kg.." or "with more longitudinal input I can increase the forward speed with respect of the pitch limit" and so on) and do not use cues that need particular representation (i.e. sensations, smelling, and so on), so it is possible to capture it within an appropriate Data Base (the so called Knowledge Base) to build an Expert System managing this knowledge.

The result of the pilot reasoning is the sequence of the test point carried out, for each test a lot of data are available to identify starting condition, piloting action, helicopter handling and the pilot judgement about the results of the manoeuvres.

4 The CBR approach

Our research elicited Case-Based Reasoning the best way to model the knowledge the pilot use to carry out the manoeuvre, describing the system pilot-helicopter in terms of *condition* that determine a *piloting action* that cause an *effect* on the helicopter behaviour.

4.1 What is CBR?

Case-Based Reasoning is both a paradigm for computer-based problem solvers and a model of human cognition. The central idea is that the problem solver reuses the solution from some past case to solve a current problem.

[2] An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors [2].

4.1.1 CBR as a computer program paradigm

As a paradigm for computer-based problem solvers the basic steps in CBR are:

- Retrieving a past case (i.e. a problem and its solution) that resembles the current problem. Past cases reside in case memory. Case memory is a data base that contains rich descriptions of prior cases stored as units. Retrieving a past case involves determining what features of a problem should be considered when looking for similar cases and how to measure degrees of similarity. This is referred to as the Indexing Problem.
- Adapting the past solution to the current situation. Although the past case is similar to the current one it may not be identical. If not, the past solution may have to be adjusted slightly to account for differences between the two problems. This step is so called Case Adaptation.
- Applying the adapted solution and evaluating the results.
- Updating case memory. If the adapted solution works properly, a new case (composed of the problem just solved and the solution used) can be formed. If the solution at first fails, but it can be repaired, the new case is composed of the problem just solved and the repaired solution. This new case is stored within the memory so that the new solution will be available for retrieval during future problem solving. In this way the system becomes more competent and efficient as it gains experience. This step is also part of the Indexing Problem.

Not all case-based problem solvers use all the steps.

In some, there is no adaptation steps: the retrieved solution is already known to be good enough without adaptation, as in the application object of this paper.

In others, there is no memory update step: the case memory is mature and provides adequate coverage for problems in the domain.

In order to verify if a problem could be solved with CBR these four condition shall be checked:

1. The set of possible solution is finite.
2. Every case can be described by a sufficient set of data.
3. It is possible to build a learning algorithm.
4. It is possible to build a retrieval algorithm to looking for the

information within the memorised cases.

4.1.2 CBR as a model of human cognition

As a model of human cognition, some argue that CBR is the basic cognitive process by which people solve problem and get about the world.

Certainly, we have all had the experience of remembering some past situation when confronted with a problem and of finding that reminding helpful in solving the current problem.

Whether or not CBR is a universal model of human cognition, there are many situations in which people use CBR to solve problems. Designers usually rely on libraries of past design to provide them with suggestions for new design problems, foe example. The design process often resembles the four steps sketched above.

4.2 CBR in our model

To approach the problem with this technique we considered each H-V manoeuvre as a single *case*.

The manoeuvre may be interpretated as the sequence of four phases:

1. Starting Condition
2. Transition to powered descent (after engine failure)
3. Steady powered descent
4. Final Manoeuvre (Flare + Touch Down)

Each of these phases is memorised as many *subcases* within the KB, but it is obviously indexed by the same "case number", in such a way that the ES may realise two levels of reasoning (retrieving case and/or subcase).

Different problem can be treated, so the cases can have different interpretation, the most important are three:

1st PROBLEM:

Is this flight condition outside the H-V area?

SOLUTION:

The ES returns the distribution of <u>the most similar case,</u> given in form of manoeuvre final result versus similarity, to decide if a safe recovery manoeuvre is flyable with the input condition.

2nd PROBLEM:

Has this flight condition reached the helicopter limit for this kind of manoeuvre?

SOLUTION

The ES returns the distribution of <u>the most similar case,</u> given in form of manoeuvre final result versus similarity, together with the limits sorted by criticity.

3rd PROBLEM:

What are the effect of this control displacement while the helicopter is in hover (high hover point of H-V diagram)?

SOLUTION:

The ES returns the Steady Descent phase associated to the Transition phases with the most similar control displacement and similar weight / ambient condition.

In addition, a fourth problem is similar to the third one but handling the final manoeuvre.

These tools may be used to simulate the helicopter flight through the same sequence of conditions as far as the pilot would choose to identify the H-V limitations.

An other application of this tool is to check the effect of the abuse case (in terms of controls movement and/or intervention delay) to assess the safety margin of the manoeuvre and/or to optimise it.

The developed ES do not present an Adaptation Phase (see paragraph 4.1.1) and it consists of two principal components: the <u>Knowledge Base</u> and the <u>Retrieval Algorithm,</u> jointly to the <u>rule for KB updating</u>.

5 The Knowledge Base

The knowledge base of this Expert System originates from the analysis of about hundred H-V tests carried out with a twin engines helicopter, at various combination of weights and ambient conditions.

To create a consistent Data Base the whole set of traces (an example is given in Figure 2) of the relevant parameters recorded in flight have been examinated to identify the information that characterise each phase of the H-V manoeuvre.

Of course a unique way to read the signals and input the DB were studied. The standardisation of the key values required to represent the case is a very critical phase in the process of building this (and any) ES. Reasoning capability and clearness of the retrieved solution, move towards the choices carried out at this step.

5.1 Data acquisition and standardisation

For each subcase-table the most significant signal interpretations are described in this chapter.

Starting Condition are very easy to identify, they consist in GW, Hp, OAT, Height AGL, Power Required, Rotor RPM.

During the Transition to powered descent the signals that may show ambiguous interpretation are the longitudinal and collective control movements. About the cyclic controls the maximum increment has been recorded, while for the collective the maximum push down has been measured; if the controls have been adjusted during the transition only the max value has been taken in account.

Steady powered descent has been identified by the vertical velocity and the minimum pitch attitude recorded during the condition.

The Final Manoeuvre is the most critical to recognise via standard information. We split it in two phases: *flare* and *touch down*. The flare is clearly identified by a load factor increment at a few feet from the ground. This effect is preceded by a pull in of the longitudinal cyclic and is followed by an increment of pitch attitude and normally collective and torque value increase at the same time.

Due to the lack of a load factor peak, the flare is not recognisable, hence this means that the landing has been performed without it and there is a regular deceleration with a gradual increment of the load factor up to the touch-down. In this case the DB fields are filled with the information that characterise this manoeuvre. Therefore the data definition is different , as explained below.

If a flare has been carried out

Initial and final time: when load factor increase and become 1.0.
load factor: maximum value during flare.
Pitch Attitude: maximum value recognise in the whole final manoeuvre.
Torque maximum value recognise in flare, and the related collective position.
Cyclic Longitudinal: the .variation before the starting of the flare.

If a flare has not been carried out

Initial time: when load factor start to increase together with reduction of the rate of descent (usually these two conditions collapse in one point), the related height AGL shall be reported.
final time: do not fill, so it is clear that there is no flare.

When the helicopter lands with high pitch main gear touches before nose gear. The time of landing is the first one. The second time is reported together with the related load factor.

The canonical procedure should be lead to land with the helicopter levelled, so this information is an alert about the goodness of the manoeuvre.

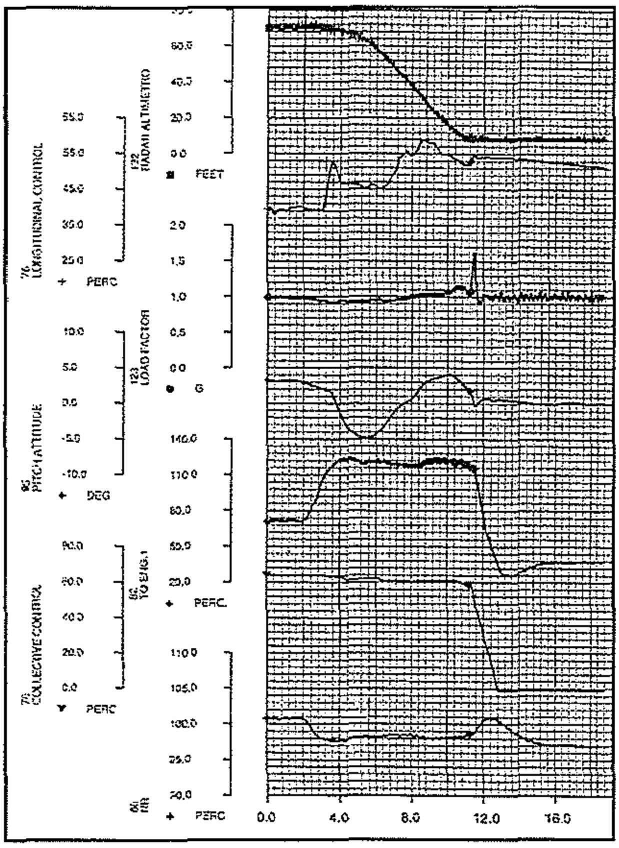

Figure 2 Emergency landing with flare

The pilot judgement of the performed procedure is stated as *negative* or *positive,* this information, together with the load factor at touch down and the pitch attitude will use to evaluate the *score* of the manoeuvre, through the flow chart showed in Figure 3, implemented by one of the updating query of the data base.

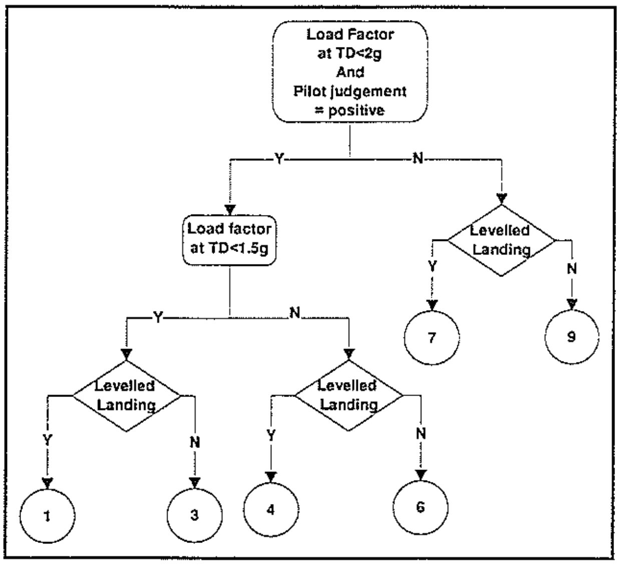

Figure 3 Score determination process

5.2 Implementation of the DB

All the data previous listed have been gathered and stored in a dedicated data base build with Access 97.

The structure of the DB reflects the way in which they are collected, so each case has been stored in five tables (one more for general description) that are related by a common key that is of course the number of the case.

To fill in the field of the table dedicated dialog window has been created, with appropriate filter to avoid the input of bad value (out of range or something like that).

An example of these windows is shown in the following figures:

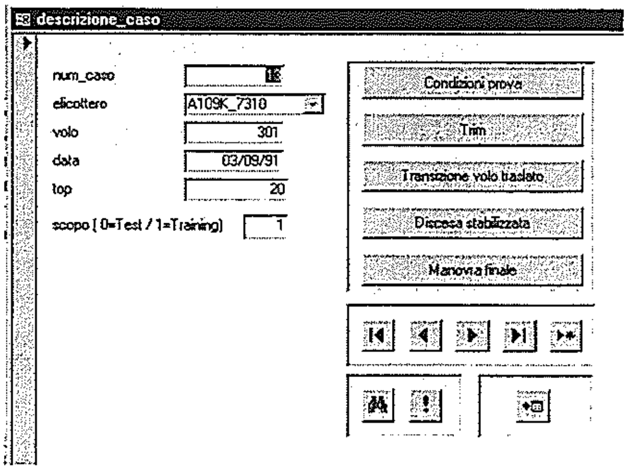

Figure 4 Master input dialog box

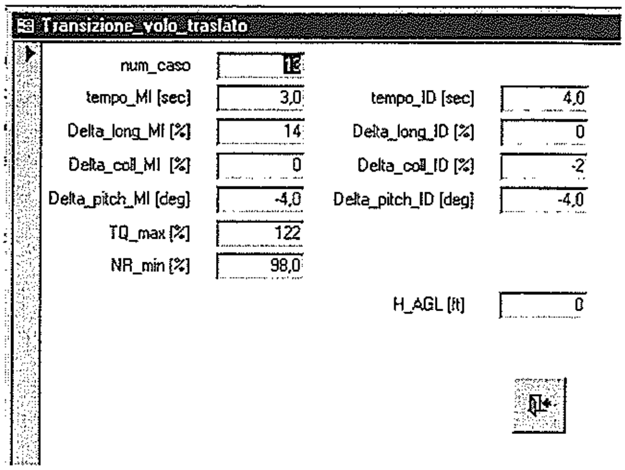

Figure 5 Transition dialog box

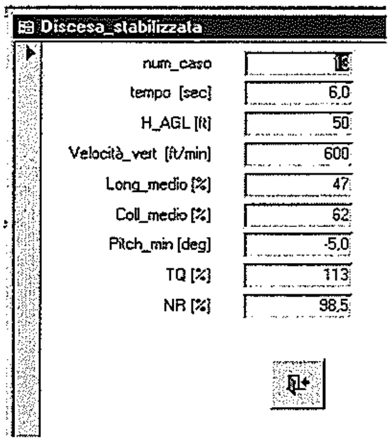

Figure 6 Descent dialog box

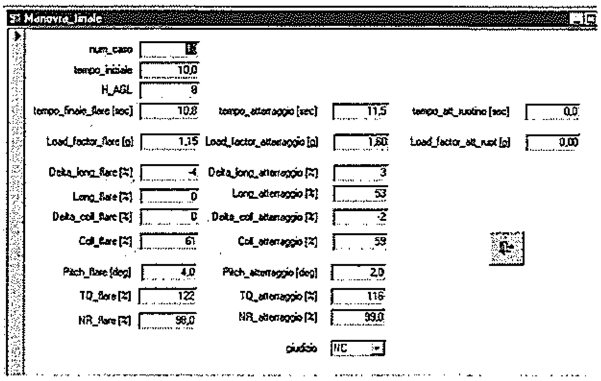

Figure 7 Final Manoeuvre dialog box

These tables do not incorporate only the mentioned input values, but they have some more field to contain additional essential computed parameters.

The calculation of these values has been performed by some updating queries routines that fetch the needed values from the various tables and fill the required field.

The retrieval algorithm use some of these data to looking for the similar case. For each tables the list of them follows.

Starting Condition :

Sigma (relative air density)
GW/sigma
MCP. margin
2.5min margin

Transition to descent

Pitch vs Long
Acceleration
Accel vs Long

Steady powered descent

Power required
Delta_Height
Delta_Height vs Velocity

Final Manoeuvre

Touch Down Velocity
Deceleration
Deceleration vs Controls
Pitch vs Controls

6 The Retrieval Algorithm

The information within the data base will be inferred by a retrieval algorithm that will return the case closer to the flight condition gave in input to verify the H-V limitation, or to create a new case, mixing control movement and single sub-case to return whether or not a recovery manoeuvre can be handled at conditions not included in the DB.

RA search through the case space comparing the input (the problem to be solved, the so called *goal*) with the stored cases to measure the similarity between them and return the list of the best ones.

Each case is constituted by many attributes, for each of them the rate of similarity is computed as the difference respect to a defined normal distribution of values, while the similarity of the case is the weighted averaged sum. Both formulas are reported below.

To realise a more efficient search, the cases in the data base are sorted by importance of attribute.

$$\text{similarity}_{ni} = e^{-\frac{(case_n attribute_i - goal\_attribute_i)^2}{\sigma^2}}$$

$$similarity_n = \sum_{i=1}^{k} \frac{w_i * similarity_{ni}}{k}$$

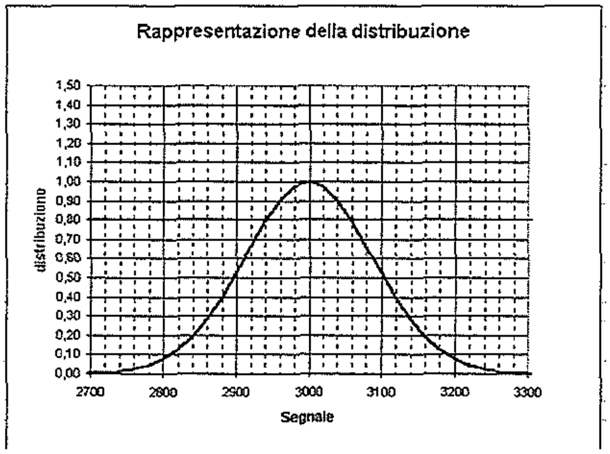

Figure 8 Normal distribution to compute similarity

The ES is able to perform different level of reasoning, this has been obtained by the implementation of three retrieval algorithms:

- Global Case Retrieval.
- CBR Piloting Simulation.
- Stochastic Piloting Simulation.

Each algorithm is schematically described in a meta-language, together with some considerations about its behaviour.

6.1 Global Case Retrieval

This algorithm perform the first level of reasoning: running it with different input lead to the determination of the H-V diagram by the identification of the performance limit, but it do not use pilot experience to check the feasibility of a manoeuvre. This is a second level of reasoning that is realised by the next algorithms.

INPUT
(the flight condition to be tested)
GW, Hp, OAT, Height AGL

SEARCH
(between test_condition tables)
the cases with more similar GW/sigma and height

RETURN
The relative case_number together with the final result and the degree of similarity

6.2 CBR Piloting Simulation

This algorithm use the KB to pilot the helicopter at given loading and ambient condition by the control movement input by the user. It has been implemented in three phases.

1st step

INPUT
(the flight condition to be tested)
GW, Hp, OAT, Height AGL

SEARCH
(between test_condition tables)
the cases with more similar GW/sigma or GW

RETURN
The relative case_number together with the final result and the degree of similarity split in two sets: one for GW and one for GW/sigma

2nd step (for each of the above sets)

INPUT
Longitudinal and Collective movement

SEARCH
(between Transition tables)
the cases with more similar controls changes

RETURN
The relative Transitions and the associated Steady Descent

3rd step (for each of the above sets)

COMPUTE
The still available height

INPUT
Vertical velocity and still available height

SEARCH
(between Descent and Final_manoeuvre tables)
the cases with more similar input

RETURN
The relative Final_manoeuvre together with the final result and the degree of similarity.

6.3 Stochastic Piloting Simulation

This is the most complex algorithm, it uses the KB to determine some handling laws of the helicopter to simulate the two manoeuvres of the recovery from an engine failure occurred in hovering: the transition to descent and the flare to safe landing.

It is constituted by two parts.

1st step

INPUT
(the flight condition to be tested)
GW, Hp, OAT, Height AGL

SEARCH
(between test_condition tables)
the cases with more similar GW/sigma or GW and successful final result

RETURN
The relative case_number together with the degree of similarity split in two sets as before.

2^{nd} step (for each of the above sets)

INPUT
Longitudinal and Collective movement

SEARCH
(between Transition tables)
the cases with more similar controls changes

COMPUTE
The value of ACCELvsLONG and PITCHvsLONG via the data retrieved in the Transitions selected

RETURN
The relative vertical speed, the pitch attitude variation and the height loss to stabilise the descent

SEARCH
(between Descent tables)
the cases with more similar speed and pitch

RETURN
The selected cases

3^{rd} step (for each of the above sets)

INPUT
Longitudinal and collective controls during flare and collective pull up at touch down

SEARCH
(between Final_manoeuvre tables)
the cases with more similar controls changes

COMPUTE
The value of DECperCOM and the estimated touch down speed and height required to decelerate

RETURN
The final result of the manoeuvre

7 KB updating logic

This is the learning phase of the ES job, by which it is able to infer new knowledge.

At a first glance this expert system could appear equal to a relational data-base, but it is more.

The true difference is the ability to retrieve sub-cases to solve problems by the appropriate combination of them.

For example: retrieve the starting condition from case "1" similar to the input, than the transition from case "20", the related descent from case "32"and the final manoeuvre from case "81", concatenating the four phases to build a sequence that simulate the new manoeuvre that may be added to the data-base as the new *inferred case* .

8 Running the ES

This ES is very simple to run, the set of conditions to be tested is the same to what could be planned to fly the actual helicopter.

The collection of results is recorded in dedicated files and lead to the discovery of the conditions that determines the reaching of the helicopter limits.

To test the reliability of the ES, the DB has been split in two sets: the *training* set and the *test* set: the cases of the test set has been used as input data to check the result of the ES based only on the reduced training set.

The investigation is still going on but the expected result is the definition of a *minimum required set*, this information could be used during next flight trials to limit the number of tests, reducing risks and costs.

Since the beginning of running, the behaviour of the ES were very impressive, due to its ability to treat data, to retrieve the appropriate cases and ranking them by similarity values that highlights aspects that was not directly involved in the search but that was very important the show the limits of the flight condition and to understood the reason of the (success or the failure) of the flight test.

9 Conclusion

The important results have been obtained from this research program:

- The model for the simulation of H-V manoeuvre from high hover condition, that has been demonstrated to be capable of reliable results and that can be surely improved again.
- The KB consists in a more familiar representation of the H-V test data: these information are no more contained only in the cryptic traces but the knowledge has been organised accessible DB, available to any user, the less expertise too. The Appendix deal with the topics related to the knowledge dissemination aspect.
- The whole ES is really an important tool to support data analysis leading the analyst as an expertise could do.

10 Acknowledgements

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11 Appendix: Knowledge Management

The fundamental economic resource of the present society is no more the capital nor the manufacture production but the knowledge, the "know-how", are and will be the key to be competitive and winner.

For example within our Flight Test Department a lot of data are stored in different way but the question is: "How much of this *information* become useful *knowledge* for the employers?".

KM leads to this goal, looking for anything able to extract knowledge from the information and to make it available to be learned without or minimising the expensive and precious support of the expertise people.

More precisely KM consists in any activity which purpose is the acquisition of the knowledge from own and others' experience, and the application of it to catch the goal of the Company.

This activity is realised joining technology, organisation structure and knowledge-based strategy to improve the present knowledge and to create new one.

The key of the success of this project is the development of the cognitive systems to acuire, to store and to retrieve the knowledge to learn, to solve problems and to take decision.

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