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HELICOPTER MODEL IN FLIGHT IDENTIFICATION BY A REAL TIME SELFADAPTIVE DIGITAL PROCESS

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ABSTRACT

A feasibility evaluation of an airborne electronic device that automatically identifies the helicopter transfer functions is presented.

The helicopter frequency response to its impulse response flight test data, is computed by a dedicated microprocessor. The software involed implements an adaptive algorithm that matches a preselected helicopter frequency model with the computed frequency response. This yields the best linearized model approximation to the actual system transfer function. For the selected set of state and control variables, the corresponding numerator and denominator polynomial transfer functions are computed in real time.

The basic theory of the adaptive strategy and identificator unit implementation are described in the paper.

The simulation results prove the feasibility of the in-flight identification digital process as an useful tool in solving helicopter stability and control problems.

1 - INTRODUCTION

The continuing development of helicopters covering wider flight envelops has given rise to new and different stability and control problems. In addition, operational requirements impose more stringent handling characteristics particulary for military helicopters. With regard to this it may be observed that the constantly increasing speed of attack helicopters means that the time available in making a run to a target is becoming shorter. Consequently high degree of tracking accuracy is required to insure a reasonable probability of successful attack; ease of tracking depends on stability and control characteristics involving more stringent requirements as well. Thus stability and control problems are continually present in a new helicopter's design and many of them are such that their solutions are to be found only through flight testing.

To solve these problems, a self-adaptive digital process for helicopter transfer function in-flight identification is proposed.

By recording the transient response data obtained in flight pulse testing and computing the ratio of the input-output Fourier Transforms,one obtains the helicopter frequency response.

A linear mathematical model structure, wich we assume to be the most realistic for helicopter dynamics, is matched, through a numerical optimization process minimizing quadratic cost function, with the measured system frequency response observed in a specified frequency range.

The results of this optimization procedure will be the best helicopter linearized model reflecting, in a specified frequency range, the most realistic helicopter dynamical characteristics.

The feasibility of the identification process proposed here results from the enormous progress in microprocessor technology, allowing a drastic reduction in the time required to perform the I/O basic arithmetic operations involved in the spectral processes.

Furthermore the computational time required for Fourier Transform computations extended to cover a large number of frequency points does not constitute, at the present technological state of art, a problem for a real time frequency response computation.

The first two sections of the present report are dedicated to the basic mathematical concepts regarding the algorithms used for the helicopter frequency response and for the model identification numerical processes.

The "identifier" digital unit block diagrams, as it has been proposed for its actual implementation, and the basic specification for its constituent parts are described in the third section.

The next two section are devoted to the Agusta A-109 transfer function identification from actual flight test data.

2 - HELICOPTER FREQUENCY RESPONSE COMPUTATION

The helicopter frequency response is derived as the ratio of the system response y(t) and the correspondent input forcing function r(t) Fourier Transforms:

$$G(\omega) = \frac{Y(\omega)}{R(\omega)} = \frac{F[y(t)]}{F[r(t)]} = \frac{\int_0^\infty y(t)e^{-j\omega t}dt}{\int_0^\infty r(t)e^{-j\omega t}dt}$$

Developing the complex exponential appearing in the Fourier integrals and assuming finite value for the upper integration limits, the following expressions for $Y(\omega)$ and $R(\omega)$ are obtained:

$$Y(\omega) = R_Y(\omega) + j\, I_Y(\omega)$$

$$R(\omega) = R_R(\omega) + j\, I_R(\omega)$$

and the system frequency response will be given in the from:

$$G(\omega) = M(\omega)\, e^{j\,\varphi(\omega)}$$

where $M(\omega)$ and $\varphi(\omega)$ are respectively module and phase of frequency response.

The equivalence of the steady sinusoidal and impulse transient response methods requires that the input forcing function frequency spectrum contains all the frequencies required in the correspondent sinusoidal steady measurements.

Sampling the input forcing function r(t) and the system response y(t) in a finite number (N) of uniformly spaced time intervals (T_s), the spectral function $Y(\omega)$

and $R(\omega)$ are computed as Discrete Fourier Transforms (D.F.T.) of the corresponding functions y(k) and r(k):

$$Y(\omega) = T_s \sum_{k=1}^{N} y(k)\, e^{-j\omega k T_s}$$

$$R(\omega) = T_s \sum_{k=1}^{N} r(k)\, e^{-j\omega k T_s}$$

The D.F.T.'s wich are periodic with period $2\pi/T_s$, are evaluated for a same number N_d of points selected for the identification process.

The sampling time T_s plays an important role in obtaining an exact replica of the correspondent continuous Fourier Transform and to avoid spectra aliasing.

An appropriate estimation of the input forcing function characteristic (shape, magnitude and duration) is required for satisfactory analysis results.

With regard to this the helicopter dominant time constant, derived from a preliminary dynamic investigation, must be assumed as a reference in pulse width prediction whereas the pulse magnitude must be taken to have an energy content making the helicopter response measurable, with the required resolution, by the helicopter sensors.

3 - IDENTIFICATION PROCESS

As previously introduced, the helicopter mathematical model at given flight condition can be identified by a process matching a specified transfer function structure, the reference model, with the system frequency characteristics observable in the measured frequency response.

The reference model (M) must be representative, in a selected frequency range, of the helicopter dominant behaviour described, in the complex plane, by dominant real or complex poles $p_i (i = 1,2,\ldots,n)$ and zeros $z_j (j = 1,2,\ldots,m)$; an additional exponential delay term (τ), taking into account the truncation effects on the full order system model, may be included.

The transfer function of the reference model:

$$M(s) = K \frac{\prod_{j=1}^{m} (s - z_j)}{\prod_{i=1}^{n} (s - p_i)} e^{-\tau s}$$

can be expressed in terms of first order time constants and second order undamped frequencies and damping factors wich are collected in the model parameter's vector $\underline{x}$ assumed as variable set in the identification process.

The minimization of quadratic cost function (F) involving the reference model, expressed, in the frequency domain, in terms of the variable parameter vector $\underline{x}$, has the purpose to force the reference model $M(\omega_i, \underline{x})$ to the solution $\underline{x}_{opt}$ fitting the measured frequency response $G(\omega_i)$ $(i = 1,2,\ldots, N_d)$.

In a digital process, governed by a sampling time T_s, the cost function is formulated in discrete forms:

$$F = \sum_{i=1}^{N_d} \left| G(\omega_i) - M(\omega_i, \underline{x}) \right|^2 \Delta\omega_i$$

referred to a specific state and control variable transfer ratio. The optimization strategy is implemented by the Davision-Fletcher-Powell method using, for the k-th direction search $\underline{p}(k)$, the following algorithm:

$$\underline{p}(k) = - H(k)\, \underline{g}(k)$$

where H(k) is a particular positive definite matrix and $\underline{g}(k)$ is the cost gradient vector computed at the time at which the k - th descent direction is selected; a quadratic interpolation method has been adopted to solve the line-search problem.

The rate of convergence of the single x_i's parameter vector toward the correspondent optimal value is strongly influenced by the reference model structure and the number of frequency points handed in the D.F.T. computational stage. Faster convergence to a prescribed accuracy bound, which can be estabilished in terms of the same expected cost function or gradient terminal values, means shorter computational time contributing to a real time identification process feasibility. The processor throughput characteristics play, with regard to this, an essential role. The identifier implementation proposal is considered in the next section.

4 - THE IDENTIFIER IMPLEMENTATION

The helicopter model identification process is implemented in a digital device, the identifier unit, installed in the tested helicopter. The transient data from the sensors detecting the helicopter's state and control variables involved in the identification process are multiplexed, converted in digital format and applied to the identifier input ports.

As indicated in Fig. 1, the identifier is essentially a central processor unit using real time high speed microprocessors to solve the D.F.T. and optimization algorithms discussed above.

The identifier's performances have been emulated in a computing unit employing processors of the same class proposed for the preliminary design stage, in which the dedicated microprograms were prepared and successfully tested.

The simulation was performed working on flight test data of the helicopter Agusta A - 109.

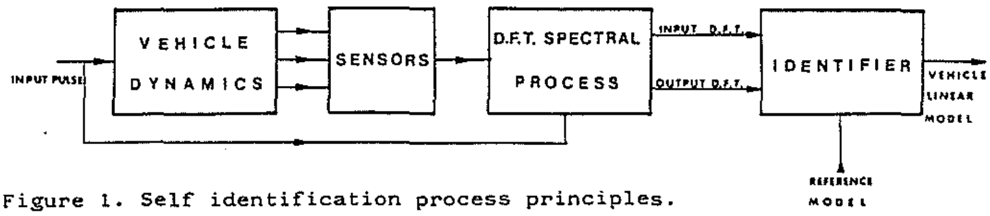

Figure 1. Self identification process principles.

5 - SYSTEM SIMULATION

The real time automatic identification of the bare Agusta A 109 transfer function is the basic objective of the simulation.

The actual helicopter impulse response,relative to the flight test condition specified in Tab.1,is given in Fig.2.

Table 1. Test flight conditions.

HELICOPTER:......................	A 109 A
WEIGHT:..........................	2600 Kg
C.G.LONGITUDINAL:................	3457 mm
C.G.LATERAL:.....................	0 mm
ALT.PRESSURE:....................	2300 ft
O.A.T.:..........................	17° C
M.R. RPM:........................	100%
FLIGHT CONFIGURATION:	Guardia di Finanza
FLIGHT CONDITION:................	N° 14, LEV 130 Kts IAS, ROLL, L.

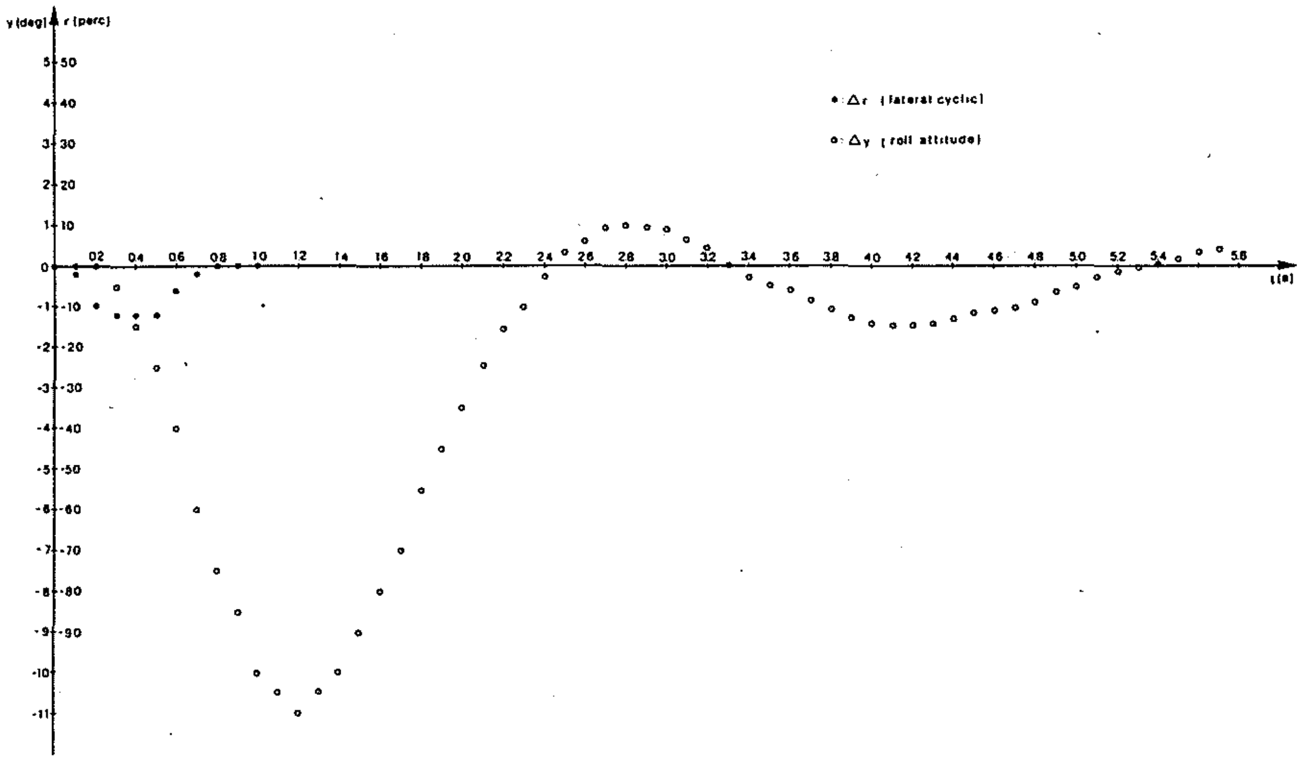

Figure 2. Input data assumed in emulation.

The simulation block diagram of Fig.3 shows the program FURISP for the spectral process applied to the I/O time funtions. The IDENTI program represent the software implementing the adaptive identifier.

The frequency response data is the output of the FURISP program and is displayed graphically in Fig.4.

The frequency response range explored in simulation was selected to cover the helicopter short period rigid modes.

A third order transfer function, including the roll convergence and dutch roll poles and a zero relative to the bank angle-lateral cyclic control transfer function, was assumed as the reference model in the identification run.

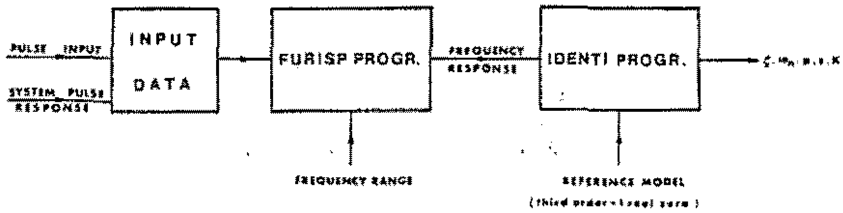

Figure 3. Simulation flow diagram.

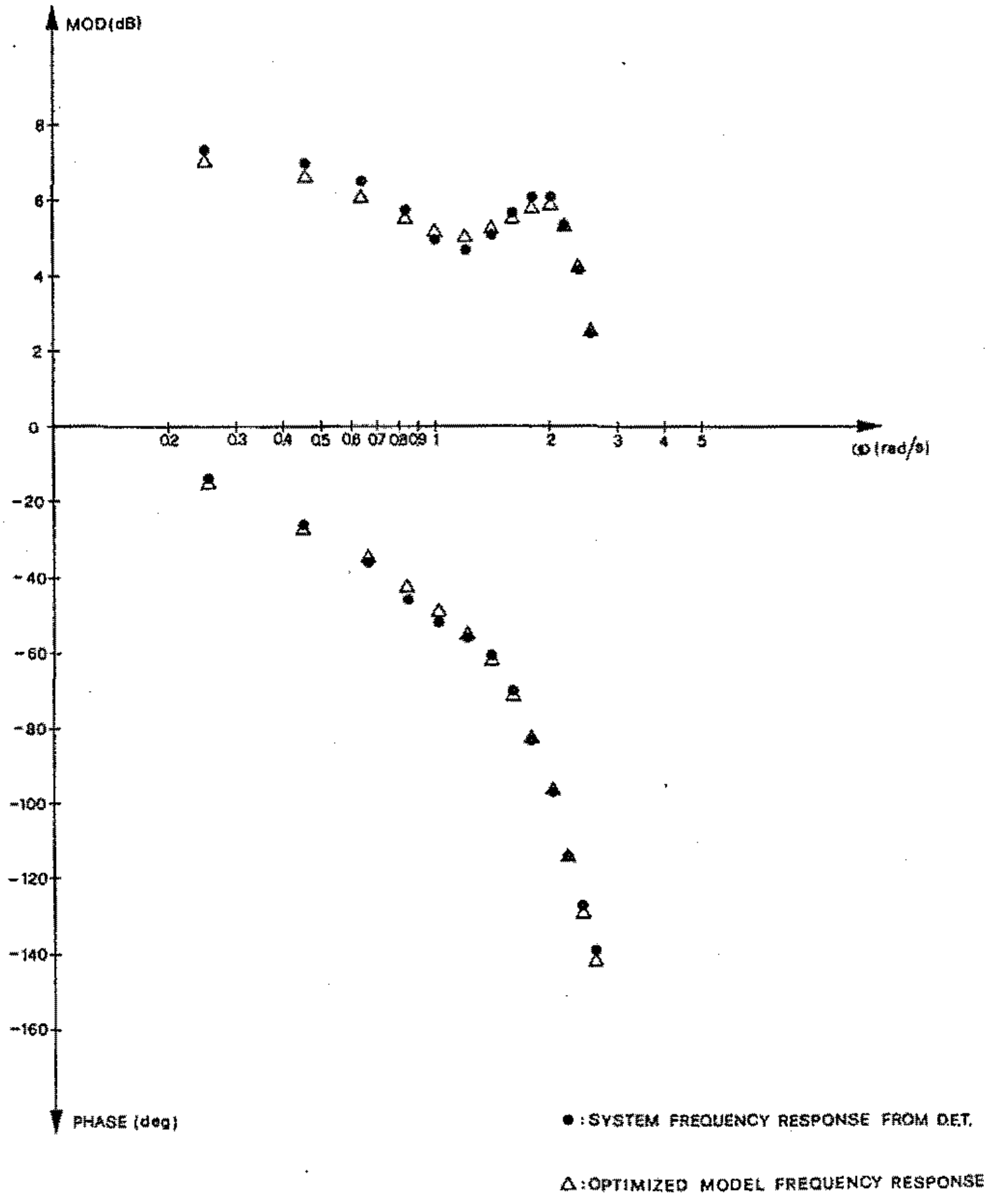

Figure 4. Frequency domain simulation results.

The parameter involved in that model are indicated in the transfer function:

$$M(s) = K \frac{(s - z)}{(s-p)(s^2 + 2\zeta\omega_n s + \omega_n^2)}$$

In Tab.2 the parameters resulting from the simulation are compared with the corresponding available data obtained in-flight-testing.

Table 2. Agusta A 109 Lateral dynamics - Bare configuration - Flight cond.: ALT.PR. 2300 ft, LEV 130 Kts IAS

Ref.par. model	Available flight test data	Identification results
K	N.A.	3.54 deg s^2/perc.
z	N.A.	-2.62 s^{-1}
p	N.A.	-0.79 s^{-1}
ζ	0.27	0.28
ω_n	1.91 rad/s	2.25 rad/s
T	3.33 s	2.91 s

N.A.: not available

In the Fig.4 and Fig.5 the simulation results are compared to those derived from flight test data.

6 - SIMULATION RESULTS DISCUSSION AND CONCLUSION

The simulation results indicate that a fairly good matching exists, in the selected frequency range, among the predicted model's parameters and those computed by the emulated identifier unit. The emulation computing time shows that, for a class of processors we employed, the complete identification process can be permormed in real time for a low order model and for a limited number of spectral points.

It is worthwhile to emphasize that a choice of a low order truncated model, when augmented with an appropriate delay exponential term, does not mean a drastic accuracy degradation in model identification. This is because the optimization process always has the effect to inject on it all the basic spectral information carried by the measured frequency response in the selected frequency range. In order to make clear this concept, suppose that the Fourier Transform of the system impulse response contains some spectral components belonging to aeroelastic effects originating from flexible rotor blades. Furthermore assume that the selected frequency range includes, besides those relative to rigid modes, the frequencies involved in the aerolastic effects. If the reference model is proposed as a truncated version of the full order model in which the pertinent high frequency modes are present, then the resulting optimized model parameters will be reflected in the basic rigid and elastic mode characteristics. This yields a realistic aeroelastic model.

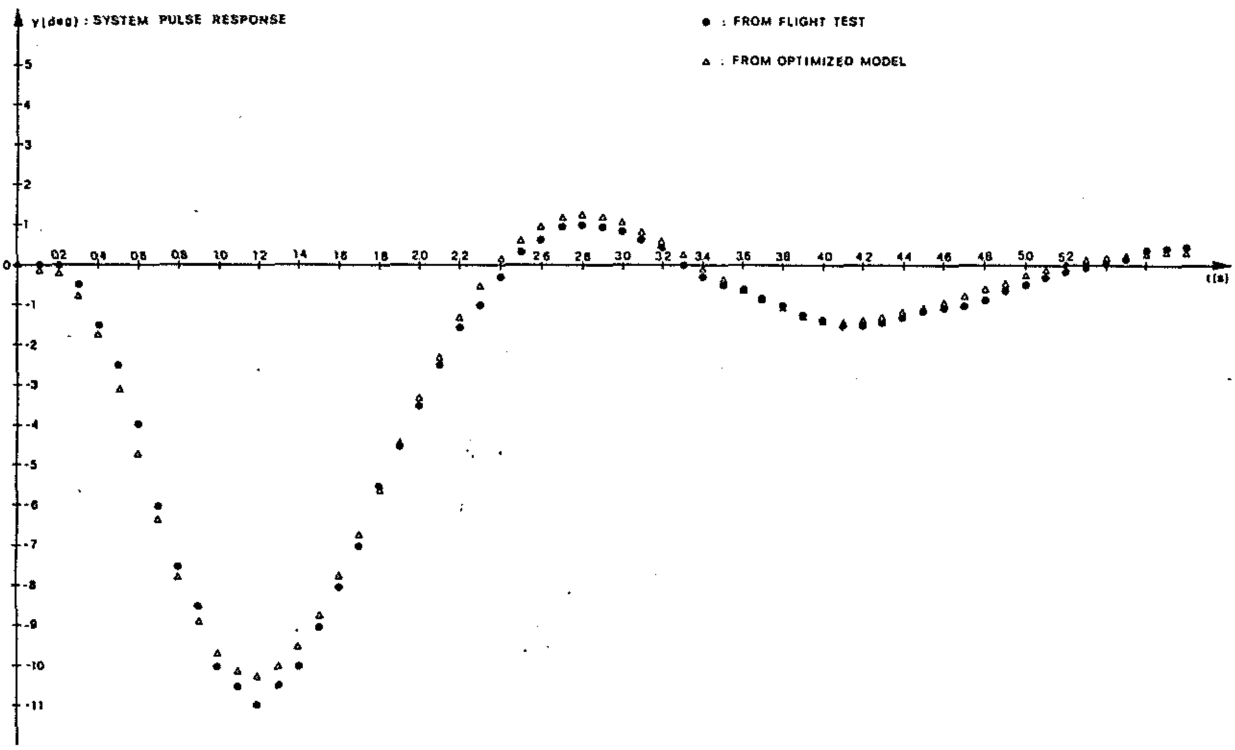

Figure 5. Time domain simulation results.

Increasing the model complexity in this case improves moderately the system modeling accuracy but at significantly greater computational time. A preliminary experimental judgement, based essentially on the observation of the cost function's or gradient's trends in the optimization process, helps to reach, for the particular problem at hand, an appropriate compromise between the model complexity and the needs of a real time implementation.

It is authors' feeling that the use of faster processors may simplify consistently the realtime problems.

Further studies with regard to this are in progress and the results will be presented in future papers.

From the above,it can be concluded that a fairly accurate helicopter model identification can be obtained in flight testing with the identifier unit proposed in this study. This may becomesa very useful experimental tool to solve stability and control problems for high performance helicopters.