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Parametric identification of an aircraft landing gear damper, by means of periodic excitation

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Abstract

Identification of nonlinear dynamical systems is most often performed by application of transient measurement signals, which are chosen in a way to resemble actual or future trajectories of the system under consideration. Another approach, analog to the experimental analysis of linear systems, is application and measurement of periodic loads in order to measure the corresponding periodic equilibrium solutions and/or outputs. This new technique, using a Bayesian estimator will be illustrated with axial measurements on a nose landing gear damper under periodic excitation. Good results were obtained for identifications on a single frequency and amplitude, but the predictive power in other parts of the parameter or state space is low.

Introduction

For landing gear manufacturing, airworthiness authorities have defined a drop-test procedure for the certification of a landing gear. These tests will produce transient signals, which resemble the operational conditions of the system during a landing. The signals can also be used for identification of prototypes. However, because of expected low applicability as a design tool, DAF Special Products initialised research on an alternative shaker-test procedure.

In literature only one monograph by Batill [2] was found that stressed the need of parameter estimators for the identification of landing gears. Batill used the well-known nonlinear unweighted least squares estimator and time integration for response computations. In Fig. 1 it can be seen how an alternative identification technique can be helpful to estimate the parameters in an assumed mathematical model of a dynamical system. In the upper half of Fig. 1 the alternative shaker test procedure is illustrated. Starting with the periodic excitation signals, the shaker-test can be performed and the state vector, some of its components, or output signals can be measured. The periodic inputs together with approximate parameters can also be input to an assumed mathematical model and by calculation of periodic solutions the measured response can be predicted. Based on the discrepancy between the measured and predicted output, parameter estimation procedures can be used to improve the approximate parameter vector.

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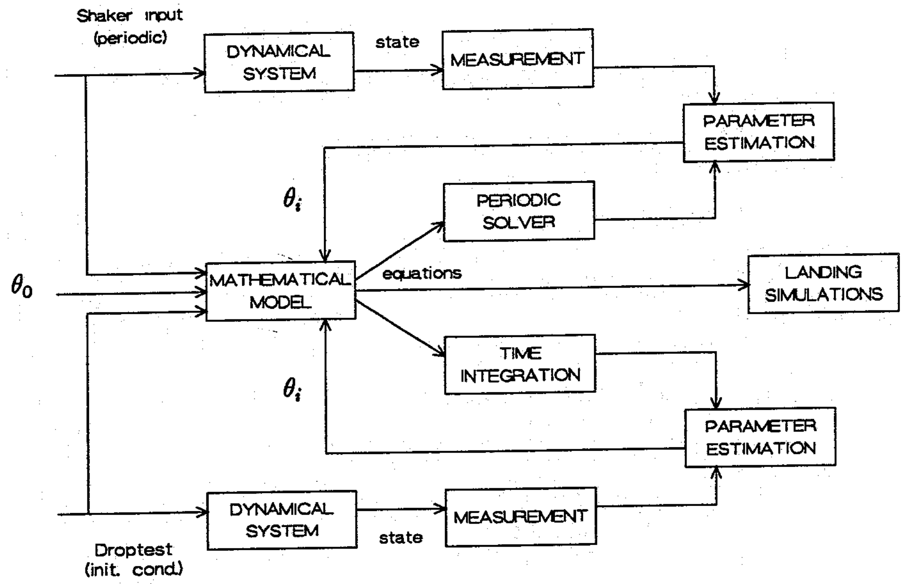


Figure 1: Drop test and alternative shaker test experiments and computations

In this project, the object of research has been constrained to modelling and identification of aircraft landing gear dampers, because of the uncertainties in the physical nonlinearities. In contrast, the geometrical nonlinearities of the complete gear can readily be modelled and simulated by multi-body dynamics codes. So the strategy is to identify the damper and use its model and final parameters for aircraft landing simulations.

Estimation method

The identification method used in this study consists of a combination of a Bayesian estimator and a periodic equilibrium solution technique based on time discretisation. For the derivation of a complete probabilistic model, several assumptions have to be made as a Bayesian estimator consists of four parts. First, the assumed deterministic mathematical model, in this case the equations of motion and the output equations

$$g(u,\dot{u},\ddot{u},x,t,\theta)=0 \tag{1}$$

$$\hat{y}=f(u,\dot{u},\ddot{u},x,t,\theta) \tag{2}$$

with displacements u, time t, forces x and parameters θ. The ODE's are solved by a periodic equilibrium solver based on finite difference techniques, Fey [4]. Second, the measured periodic data and third the assumed independent normally distributed residuals, in which modelling and measurement errors are not distinguished. Prior knowledge concerning the parameters completes the Bayesian estimator.

The transition from deterministic models to probabilistic models is discussed in Bard [1]. Here only the probabilistic form with exact measured independent variables x will be postulated. It can be shown that this estimation problem can be reduced to a maximization problem, Verbeek [6]

$$\Phi = \tfrac{1}{2}\left(-\sum_{\mu=1}^{n}\ln(\det V_\mu) - \sum_{\mu=1}^{n} e_\mu^T V_\mu^{-1} e_\mu - \ln\prod_{\alpha=1}^{l}\sigma_\alpha^2 - \sum_{\alpha=1}^{l}\frac{1}{\sigma_\alpha^2}(\theta_\alpha - \bar{\theta}_\alpha)^2\right) \quad . \qquad (3)$$

In Eq. 3 n and l stand for the number of measurements and parameters respectively, e_μ are the residuals, V_μ are the covariance matrices and σ_α and $\bar{\theta}_\alpha$ contain the prior normally distributed knowledge on the parameters θ_α. This maximization problem can be solved for the optimal parameters by modified Newton-Gauss iteration following the suggestions of Hendriks [5], which will need calculation of both predicted outputs and first order derivatives of the predicted outputs with respect to the parameters.

Application to a nose landing gear

This technique will be illustrated for axial measurements on a F16 nose landing gear damper under periodic excitation, de Jonge [3]. A schematic view of the experimental set-up for these tests is illustrated in Fig. 2. With suitable hydraulics, periodic axial forces or displacements can be applied to the landing gear. With this setup measurements are made on: the axial stroke by an MTS actuator build-in LVDT, the force applied to the wheel axle by a KISTLER piezo-electric force transducer, and the internal gas pressure of the damper by a HÖTTINGER strain gauge pressure transducer. All signals are filtered and sampled by a DIFA PC-based measurement system. The actual identification computations are performed by a FORTRAN code on a SGI workstation.

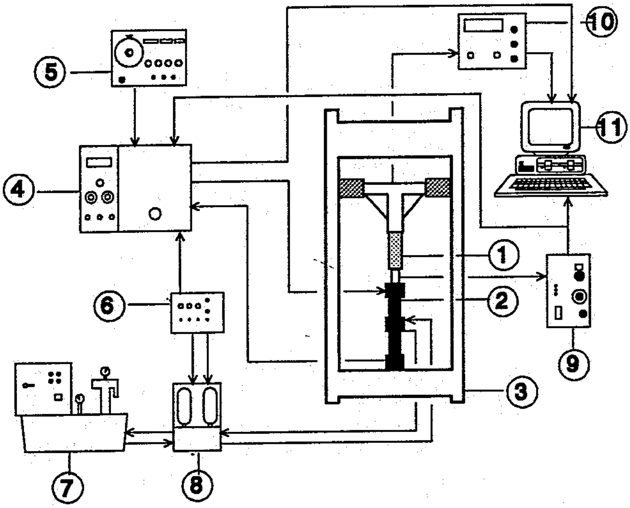
The dynamical system to be tested, a F16 nose landing gear, is modified in a way that the damping is made constant over the total stroke and that the excitation force is in line with the damper center line, in order to minimise the frictional forces. Furthermore, the initial gas pressure had to be decreased from 16 to 4 bar because of hydraulic power limitations. The mechanical behaviour of this idealised damper can be modelled by assuming the commonly used simple dynamic model, Batill [2]

$$\theta_1(\ddot{u} + \theta_2) + \theta_3|\dot{u}|\dot{u} + \theta_4\left[\frac{1}{1-\theta_5 u}\right]^{\theta_6} + (\theta_9 + \theta_{11}u^2)\arctan(\theta_{10}\dot{u}) + \theta_7 = F_{exc} \quad , \qquad (4)$$

with output equation

$$\hat{y} = u + \theta_8 \quad . \qquad (5)$$

The damping force is modelled by a squared velocity damper, the gas spring force is based on the assumption of polytropic ideal gas behaviour and the friction force



1. Landing gear
2. Actuator
3. Test frame
4. Controller
5. Signal generator
6. Remote control
7. Hydr. power supply
8. Hydr. accumulator
9. Force meas. ampl.
10. Pressure meas. ampl.
11. Pc-386/DIFA FA100

Figure 2: Experimental setup

is modelled as displacement dependent "continuous" Coulomb friction. Only the displacement of the damper is used as an output for the identification process.

Not only due to the limited hydraulic power, but also by limited time to perform and process all measurements, a set of experiments have to be defined that should cover the total available system state and parameter space. A choice is made for three piston positions: high, middle, and low. The first, high, is a position at which the static stroke summed with the dynamic amplitude is almost equal to the maximal stroke of 256 [mm]. The second, middle, is a dynamic amplitude summed to a static stroke of half the total stroke and the third, low, is similar to the first but a lower limit of almost total extension is reached. Subsequently, a selection of input parameters can be made. The frequencies selected are: 0.1, 0.2, 0.5, 1.0, and 2.0 [Hz]. The corresponding amplitudes are chosen maximal, according to limited hydraulic power. The wave form could be chosen sinusoidal or triangular, but only the first is used. The last parameter is the feedback signal to the hydraulic controller. Selected is displacement feedback, because force feedback caused severe audible stick-slip problems. The total amount of experiments selected for this study is 13.

Results

Unfortunately it is not possible to estimate all 11 parameters in Eqs. 4 and 5, from one measurement. The estimator reports dependencies between the parameters. Therefore, the identification will be split up in smaller sequential problems. First, the mass parameter θ_1 can not be estimated from these measurements because the accelerations are not significant. Second, it is assumed that the force offset θ_7 can be calculated from design drawings. These parameters and θ_2, the gravitational acceleration, and θ_8, the displacement offset, are set as constants.

As the frictional force is nearly a discontinuous function, it is very difficult to estimate its parameters. They are estimated by fitting a second order polynomial function through the friction force jumps, which are extracted directly from the data. See Fig. 3. Parameter θ_{10} is very difficult to extract from the data, only the order of magnitude could be determined. Estimations showed however that this parameter is of the same order of magnitude for all measurements, so an average value is used in the following computations. All other parameters are set to an initial value determined by geometrical and physical properties. See Table 1. It was expected

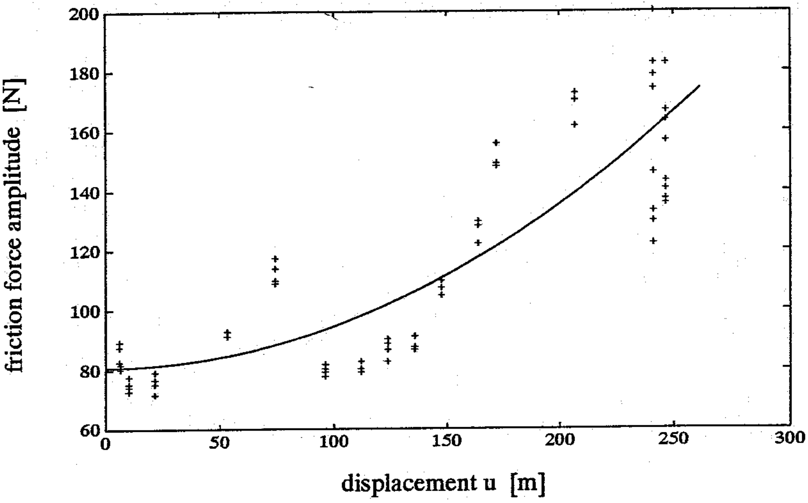


Figure 3: Polynomial fit of the friction force amplitude

θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}
25	9.81	2897	1707	3.787	1.10	-311.4	-.1405	51.6	170	870

Table 1: Initial parameters

that the remaining parameters, determining the damper and the nitrogen gas spring force could be estimated from the data. Not all experiments converged successfully and again parameter dependencies were indicated. A solution to this problem is to decrease the number of parameters to be estimated. Especially the elimination of parameter θ_5 is suited because it is a compression ratio which can be determined, with high accuracy, from design drawings. The compression ratio is estimated from a very slow experiment on a frequency of 0.04 [Hz] and set as a constant, because such an

experiment	freq. [Hz]	position	θ_4	θ_5	θ_6
920515A1	0.04	middle	1720	3.703	0.97

Table 2: New initial gas spring parameters

experiment will contain almost only gas spring forces, see Table 2. Now the remaining parameters can be fitted for all 13 experiments. The identifications successfully converge in about 6 iterations, Table 3. The residuals are in the order of millimeters or 3 % of the excitation amplitude, which is acceptable. A typical example of inputs, outputs, residuals, or parameter histories can be seen in Fig. 4. It can be concluded that only parameter θ_6, the polytropic gas exponent, meets the assumptions as it is in the range of 1.0 (isotherm) to 1.4 (isentropic) for all experiments. It is obvious that the damping parameter can not be estimated from these data as very large and even negative values occur in the output. This might be caused by small damper forces or one of the following problems. The output values for parameter θ_4, the spring preload, varies by a factor 2, which is too large. From these results and the deterministic nature of the residuals it can be concluded that the assumption of polytropic gas behaviour is not valid even for low frequency experiments. So an improvement of the model is necessary and it is believed that thermodynamics and linear gas solubility in oil can not be neglected. See Fig. 5.

experiment	freq. [Hz]	position	θ_3	θ_4	θ_6	residual [m]
920129A1	0.1	middle	89842	1458	1.10	8e-3
920129L1	0.2	high	53637	1210	1.17	6e-3
920129X1	0.5	high	21835	918	1.21	2e-3
920129Y1	1.0	high	15342	824	1.16	0.8e-3
920313A1	2.0	high	7787	1112	1.11	0.3e-3
920130A1	0.2	middle	25154	1453	1.23	3e-3
920130B1	0.5	middle	4541	1393	1.26	2e-3
920130C1	1.0	middle	2408	1390	1.26	0.8e-3
920313B1	2.0	middle	-68	1308	1.34	1e-3
920130E1	0.2	low	15424	1532	1.25	4e-3
920130F1	0.5	low	3938	1644	1.30	3e-3
920130G1	1.0	low	2851	1691	1.31	0.8e-3
920313C1	2.0	low	-195	1692	1.40	0.6e-3

Table 3: Damper and gas spring parameters

Conclusions

From this study the following conclusions can be drawn:

- The friction in the damper is not neglectable and can be modelled as a quadratic function of the stroke.
- Identification of all parameters from a single experiment is not possible, good initial values and sequential identification of a subset of the parameters is necessary.
- The assumed mathematical model for this landing gear is applicable for a single experiment as all residuals are small. However, over the total state or parameter space, the predictive value of the model with any of the converged parameter sets is low, so an improvement of the model is necessary and can probably be found by adding thermodynamics and solubility of gas in oil.
- Future research will be focussed on improvement of the model, to be able to make predictions in the complete tested state and parameter space or preferably even outside it. The method will be extended to use all experimental data in one identification.

References

[1] Y. Bard. *Nonlinear Parameter Estimation.* Academic Press, 1974.

[2] S.M. Batill and J.M. Bacarro. Modeling and identification of nonlinear dynamic systems with application to aircraft landing gear. In *Structures, structural dynamics and materials conference, 29th, Williamsburg, VA*, pages 871–884. AIAA, April 18-20 1988.

[3] T.W.G. de Jonge. Experimentele modelvorming van een vliegtuig landingsgestel gebruik makend van periodieke excitatie. Master's thesis WFW 92.088, Eindhoven University of Technology, August 1992. In dutch.

[4] R.H.B. Fey. *Steady-state behaviour of reduced dynamic systems with local nonlinearities.* PhD thesis, Eindhoven University of Technology, 1992.

[5] M.A.N.H. Hendriks. *Identification of the mechanical behaviour of solid materials.* PhD thesis, Eindhoven University of Technology, 1991.

[6] G. Verbeek, A. de Kraker, and D.H. van Campen. Identification of mechanical systems by means of periodic excitation. In *Identification of nonlinear mechanical systems from dynamic tests*, page 8. Euromech 280, Lyon, Balkema: Rotterdam, October 28-31 1991.

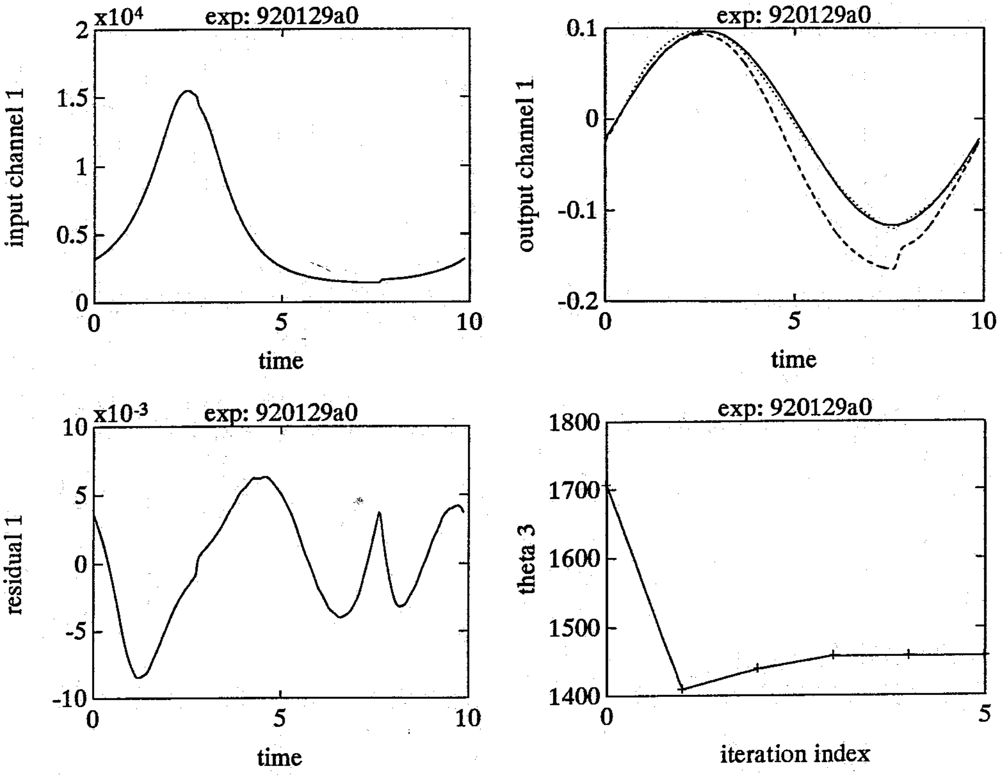


Figure 4: Typical identification results

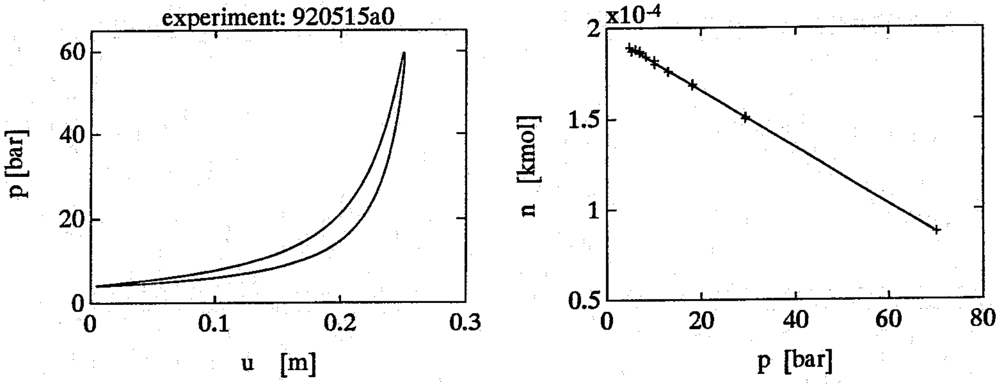


Figure 5: pressure-displacement diagram — solubility of gas