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PARAMETRIC MODELS FOR BO-105 HELICOPTER FROM ITERATIVE MULTI INPUT/MULTI OUTPUT ALGORITHMS

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Abstract

In this paper parametric transfer function models are evaluated for BO-105 helicopter using iterative multi input/multi output algorithms in frequency domain. The accuracy of the identified models are presented in bode diagrams. The identified results are compared with those estimated by the working group 18 of AGARD.

1.0 Introduction

At the TUD and NLR, system identification for fixed wing aircraft has been practiced for many years. So far time-domain techniques have been the main approach [1]. However, for helicopters, the coupling between symmetric and asymmetric movements (mainly due to the presence of the rotor) and the extra degrees of freedom of the rotor (flapping and lead-lag hinges) result in models, with a large number of parameters. Simultaneous estimation of all these parameters poses a big problem. Some of these problems can be reduced, using frequency-domain techniques. Some of the key benefits of frequency-domain analyses are:

- The coupling properties of MISO-systems can be conditioned to multiple SISO-system, thereby giving greater insight into the behavior of the system and making it possible to identify smaller models.

- The "quality" of the identified non-parametric transfer-functions can be assessed, via the coherence-function.

- The frequency range of fit can be restricted and/or frequency-weighting can be applied.

- The model structure (transfer-functions) can be based on visual inspection of the non-parametric transfer-functions.

- The non-parametric transfer-functions are unbiased in the presence of measurement and process noise.

- Time-delays can be estimated directly. Higher order models with widely spaced dynamic modes (e.g. fuselage and rotor modes) can be identified more easily.

- Different input signal performance can be compared before conducting system identification

For these reasons a software-package for frequency-domain analyses and system identification for helicopters was developed, on a personal computer, using Matlab 4.0 for Windows. These algorithms are based on the new theoretical and software developments at TUD [2 to 6]. Extensive graphical user interfaces with on-line help facilities were built to facilitate the interaction between the analyst and the computer. As frequency domain analyses is graphics intensive, user friendly graphic routines are implemented for good insight. The package is built in a modular fashion:

First the time history records are Fourier-transformed and the MIMO system is conditioned to multiple SISO-systems by an iterative procedure resulting in partial PSD coherence and non-parametric frequency responses. The PSD and frequency responses are smoothed to reduce their variances. Different smoothing algorithms have been implemented for this purpose. Once they are calculated, the (partial) PSD, coherence and frequency responses can be visualized conveniently with various plot options. From these plots, the analyst is able to determine whether the conditioning was adequate or whether the number or order of the inputs should be adapted for adequate modelling.

The next step in the identification process is to find parametric transfer-functions, that accurately describe the non-parametric frequency responses. All parametric transfer-functions must have one common denominator, since the ultimate goal is to find one state-space model, combining all transfer-functions. The denominator is built from a number of first- and second-order subsystems. For each subsystem, corresponding eigen-movements exist. Often only a few states are excited by a particular subsystem, for example, the dutch-roll (second order) mainly results in the rolling and yawing. In each transfer-function, some subsystems are more dominant than the others. If in two transfer-functions the same subsystems are dominant, these transfer-functions are fitted simultaneously.

In order to determine the model structure for a specific transfer-function, the parametric model is built in a stepwise manner from all possible influencing modes. This can be achieved by the analyst by clicking checkboxes corresponding to the desired modes (possibly including a time delay) in a menu with the aid of a mouse. At the same time the analyst can visually inspect the resulting bode plots which are instantaneously updated and displayed. In this way the analyst can iteratively build the model structure to the desired degree of adequacy. The procedure can be repeated for all possible transfer functions. These are updated to obtain one common denominator. Finally all transfer-functions are combined into one state-space model. This is readily achieved from the fitting procedure, which yields one common denominator for all transfer-functions. The analyst can then conduct time domain simulation to verify his model.

In this paper the parametric models were developed for the BO-105 helicopter and the accuracy of the models are presented in bode diagrams for various combination of control inputs (lateral, longitudinal and pedal) to outputs (measured rates and speed components). The identified models are compared with those obtained by WG-18 of AGARD [7].

2.0 Results and discussion

In this paper the discussion into the theoretical and software developemnt is not done. The readers are referred to the details given in papers [2 to 6]. Only the intermediate and end results are presented.

The parametric models were evaluated in the form of conditioned transfer function models. That is, the secondary inputs were removed by conditioning process to keep the variances in the estimates to minimum possible. In each evaluation of the transfer function model, the judgement of the accuracy is made on the obtained coherence relationship. Therefore, smoothing the spectral estimates based on the available measurements is vital in getting the best available fit. Different smoothing parameters were set for *on axis* inputs and *off axis* inputs. Similarly, a relatively higher degree of smoothing was used as a result of poor relaisation of speed measurements. In each of the models presented, 2 input/single output was considered and was found to be sufficient. This judgement was exercised on the basis of output spectral decomposition. A menu selection provided by the software is reproduced here (fig 1). This enables quick view of estimated spectrum, coherence and frequency response functions. A fitting session menu interactively allows the analyst to select the appropriate structure and develop models in an interactive fashion with the aid of a *'mouse'*.

The parametric transfer function is evaluated for the following pairs and compared with the AGARD WG 18 flight data base. The approximate flight condition considered here is Altitude=3000ft, speed= 80knts, calm air.

* Pitch rate to longitudinal stick; *q to dong* (fig 2)
* Roll rate to lateral stick; *p to dlat* (fig 3)
* Yaw rate to pedal; *r to dped* (fig 4)
* Longitudinal speed to longitudinal stick; *u to dlong* (fig 5)
* Pitch rate to lateral stick; *q to dlat* (fig 6)
* Lateral speed to lateral stick; *v to dlat* (fig 7)
* Lateral speed to pedal; *v to dped* (fig 8)

The identification results are presented in the following order (figures 2 to 8):

* The time history plots for each input/output pair
* Spectral decomposition of output, that is the part of the spectral output (S33) explained by primary input (CSPKR1), secondary input (CSPKR2) and the extraneous noise (S3312).
* The partial coherence functions of the primary input (GU1), the secondary input (GU2) and their combined input in the form of mutiple coherence function (GYX2).
* The fitted frequency response function (model versus flight) with fitted frequency range.
* Time constants, damping ratios and undamped natural frequencies

An overall presentation of the identification results are given in tables 1 and 2 in respect of:

* Aperiodic Roll mode
* Phugoid motion
* Dutch roll oscillation

* Aperidoic pitch mode 1
* Aperiodic pitch mode 2
* Lead lag mode
* Rotor flap mode
* Time delay

Conclusions

The iterative multi input/multi output algorithms work quite well. The estimates are quite close to the results presented by the working group 18. The results are under further refinement.

Acknowledgements

The authors are thankful to National Aerospace Laboratory (NLR), Amsterdam and the Institute for flight mechnaics, German Aerospace Laboratory (DLR), Braunchweig this work possible.

Abbreviations

AGARD	=	Advisory Group for Aerospace Research and Development
MIMO	=	Multi-Input/Multi-Output
PSD	=	Power Spectral Density
SISO	=	Single-Input/Single-Output
TUD	=	Technical University Delft, The Netherland
NLR	=	National Aerospace Laboratory , The Netherland
DLR	=	Deutsche Forschungsanstalt fur Luft und Raumfahrt, Germany
AFDD	=	Aeroflight dynamics Directorate (US Army), USA
CERT	=	Centre d'Etudes et de Recherches de Toulouse, France
NAE	=	National Aeronautical Establishment, Canada
Glasgow	=	Glasgow university
WG-18	=	Working Group 18, on Rotorcraft system identification

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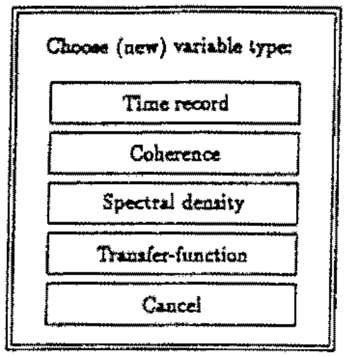
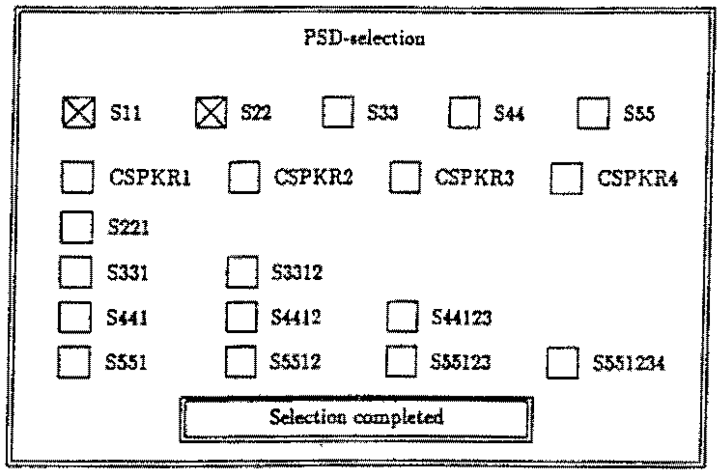
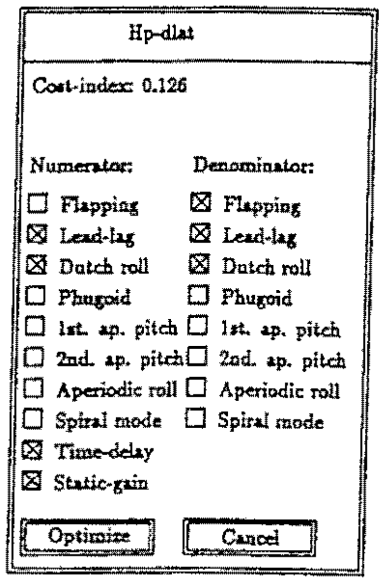


Main menu for *misoplot*: Variable type definition



Misoplot submenu: Selection of PSD-functions for printing



Menu for fitting procedure

Fig 1: MISO/MIMO Software Menu

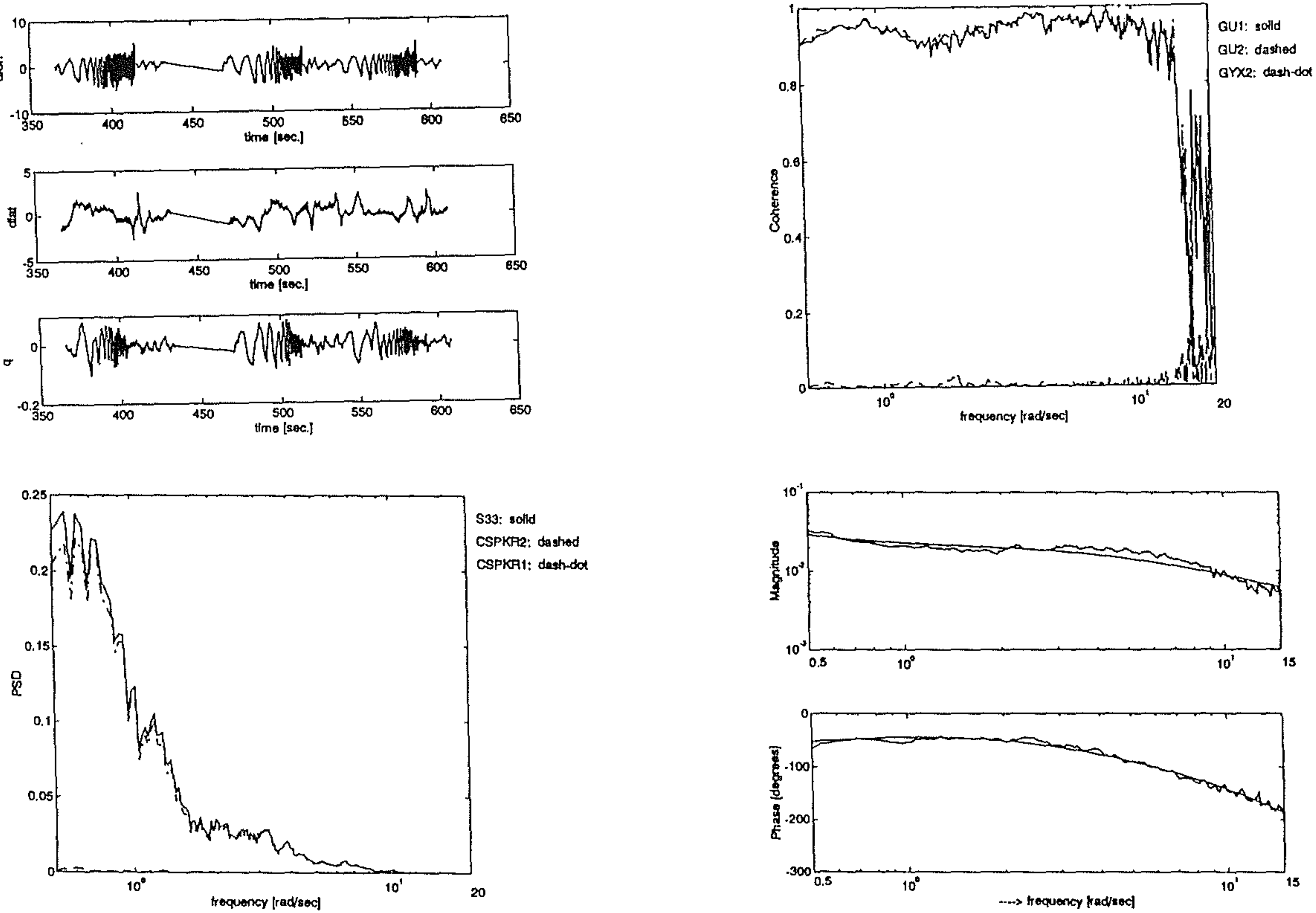


Fig 2: Comparison of BO-105 flight data and identified frequency response - dlon to q

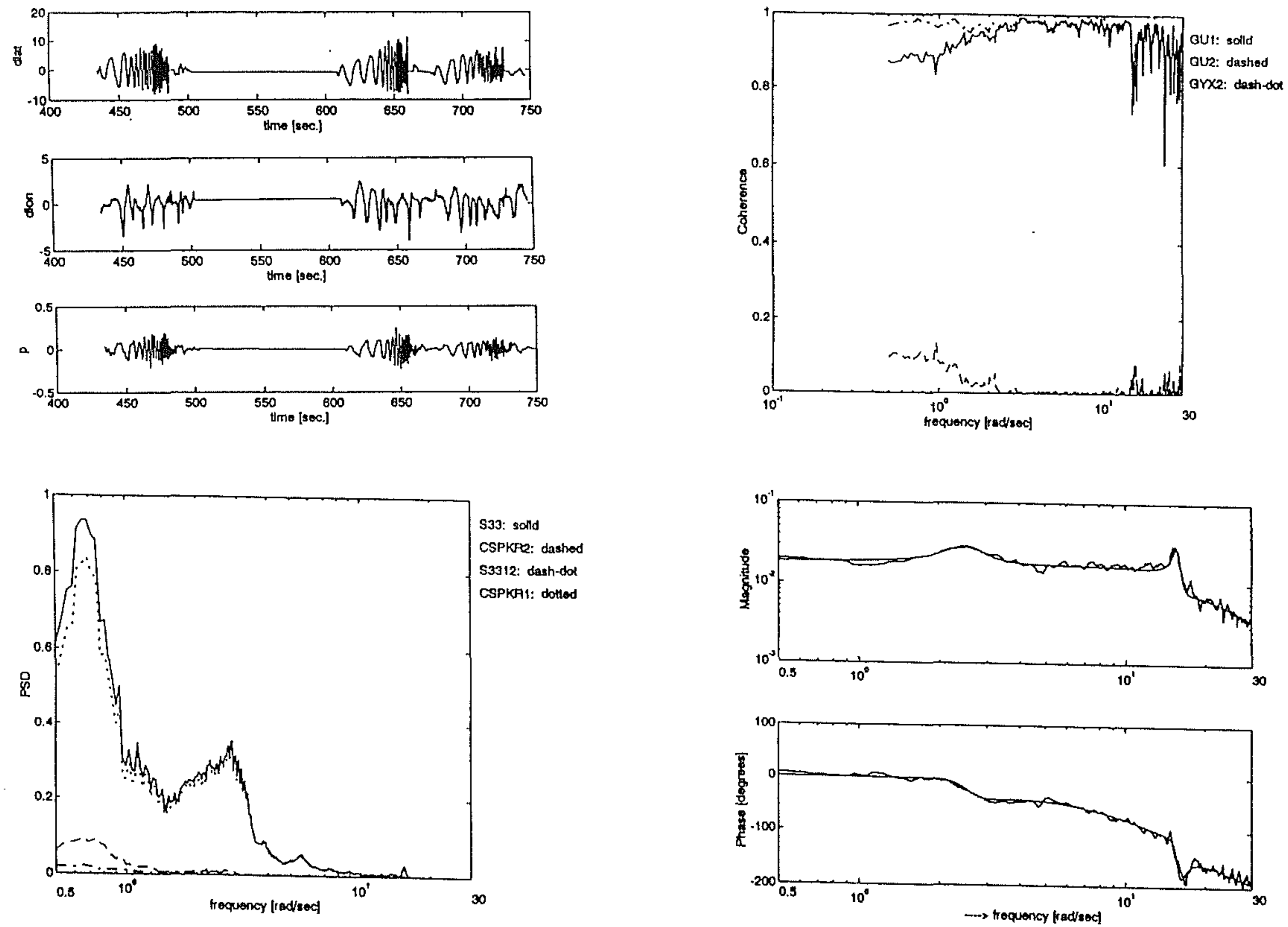


Fig 3: Comparison of BO-105 flight data and identified frequency response - dlat to p

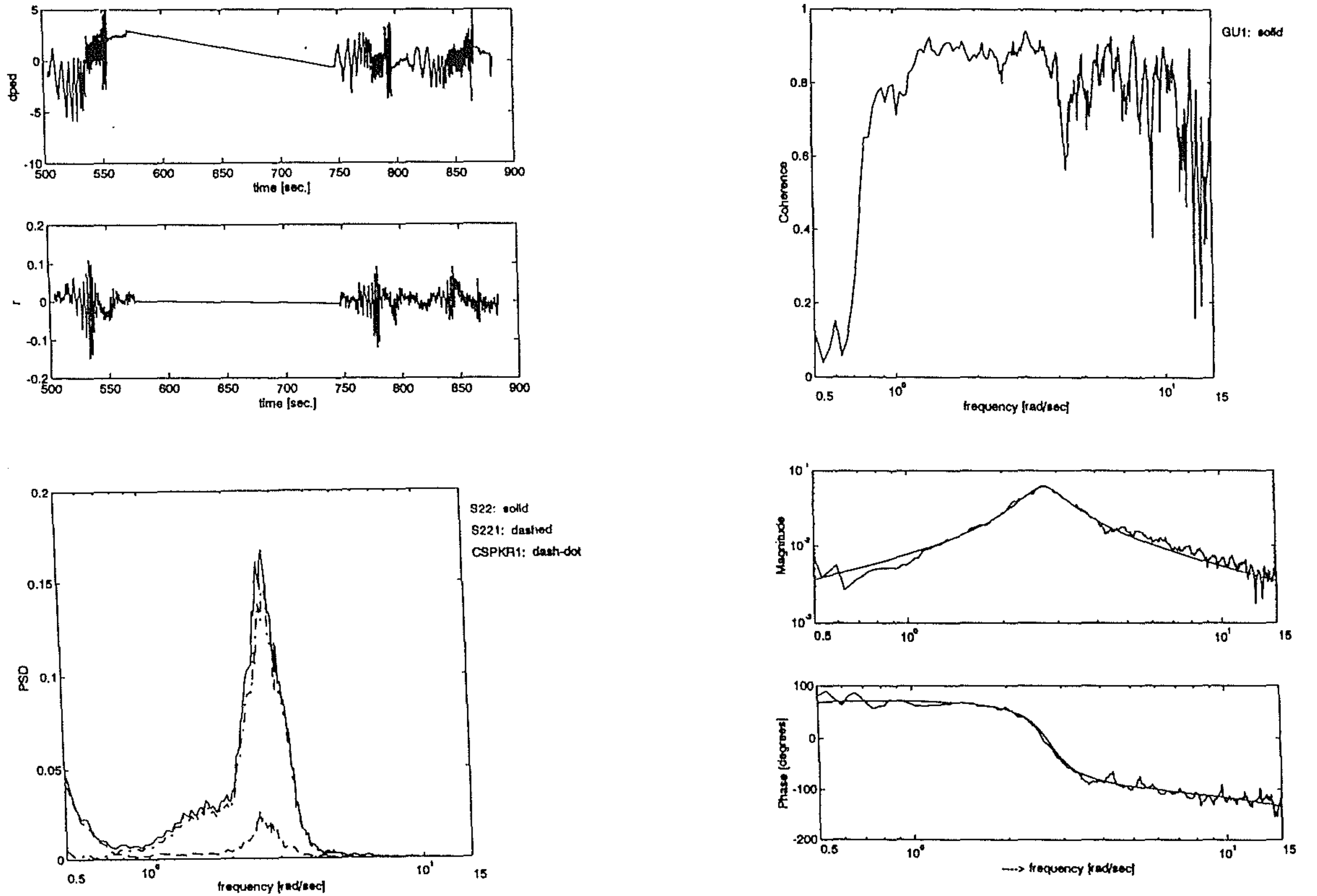


Fig 4: Comparison of BO-105 flight data and identified frequency response - dped to r

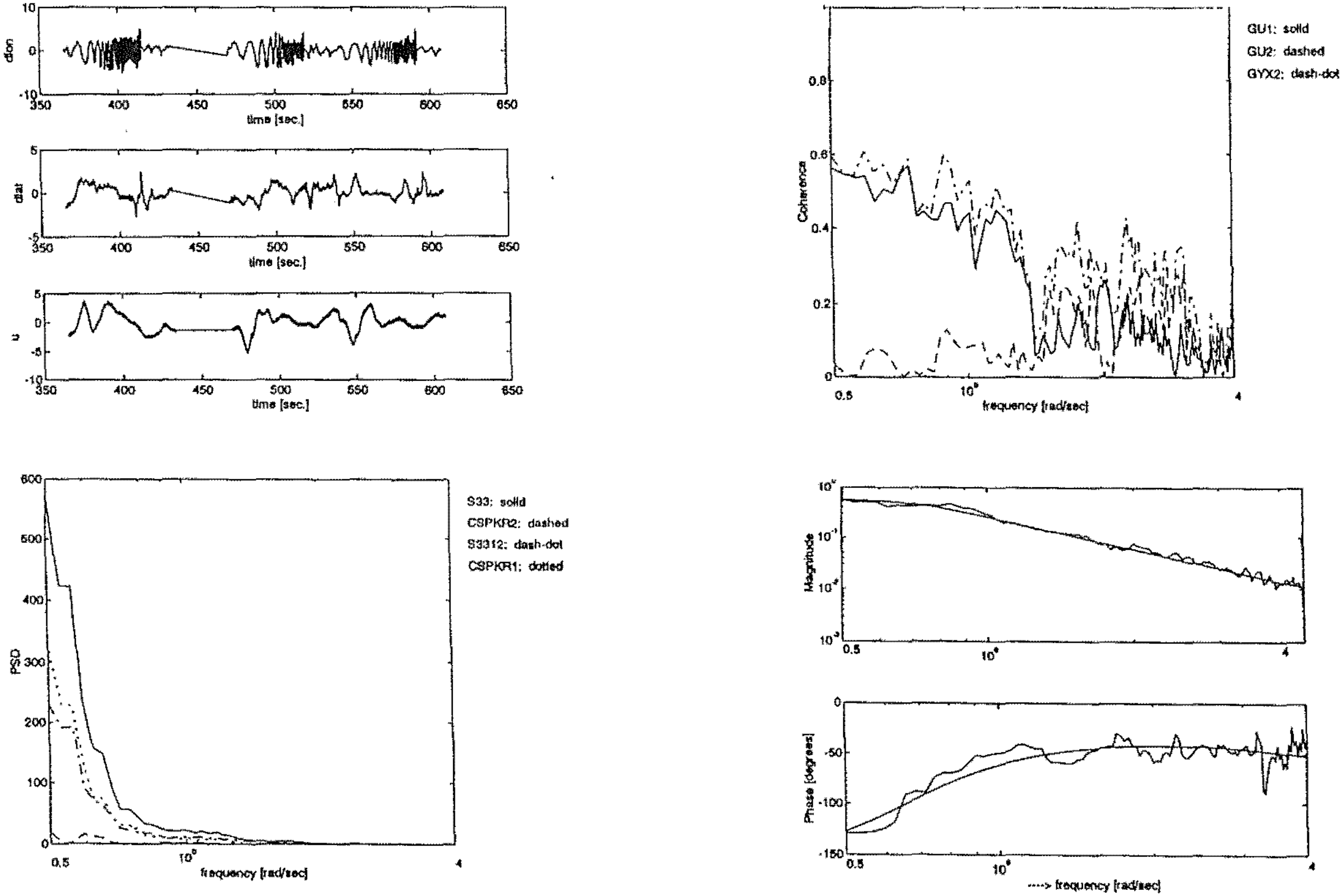


Fig 5: Comparison of BO-105 flight data and identified frequency response - dlon to u

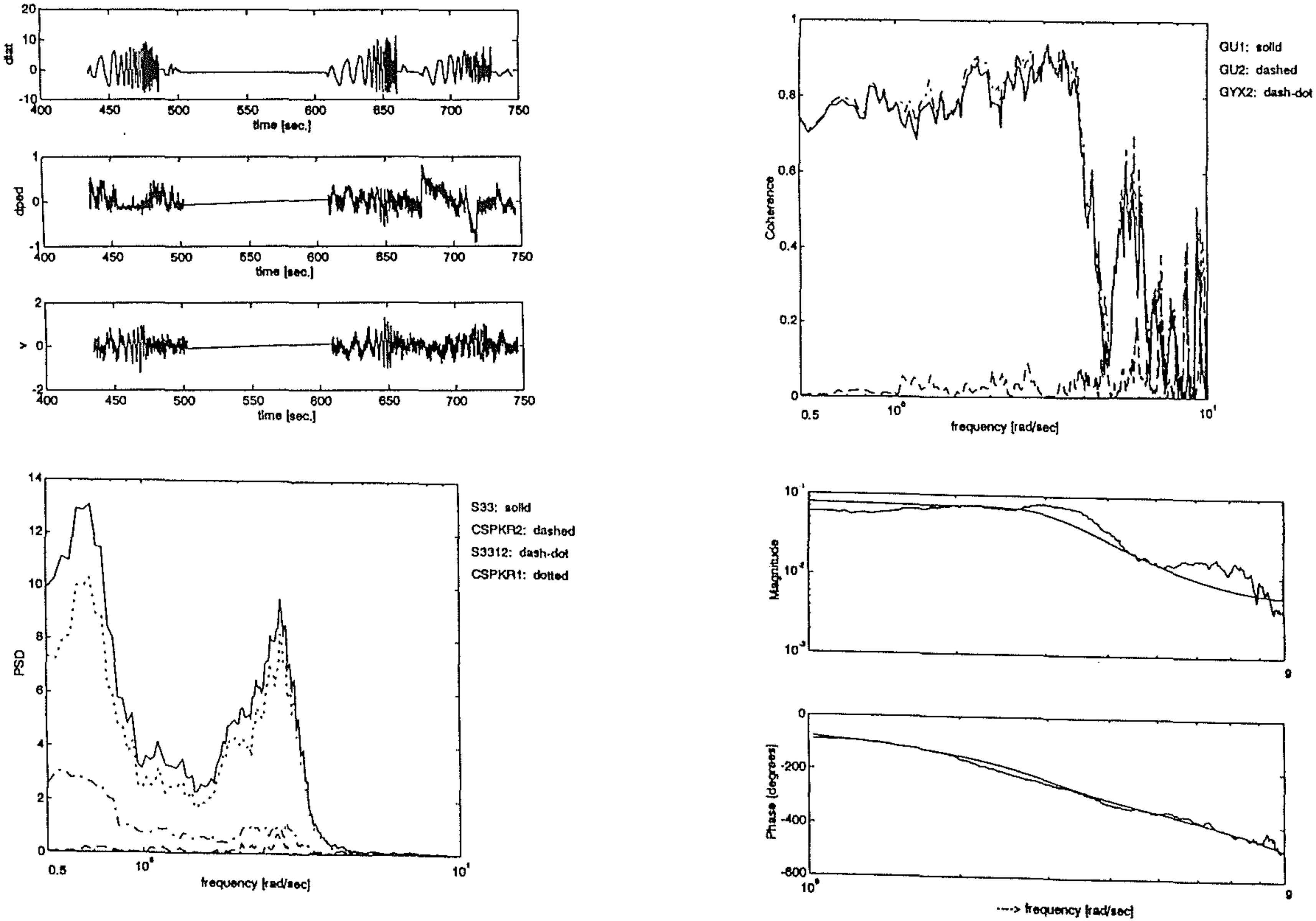


Fig 6: Comparison of BO-105 flight data and identified frequency response - dlat to v

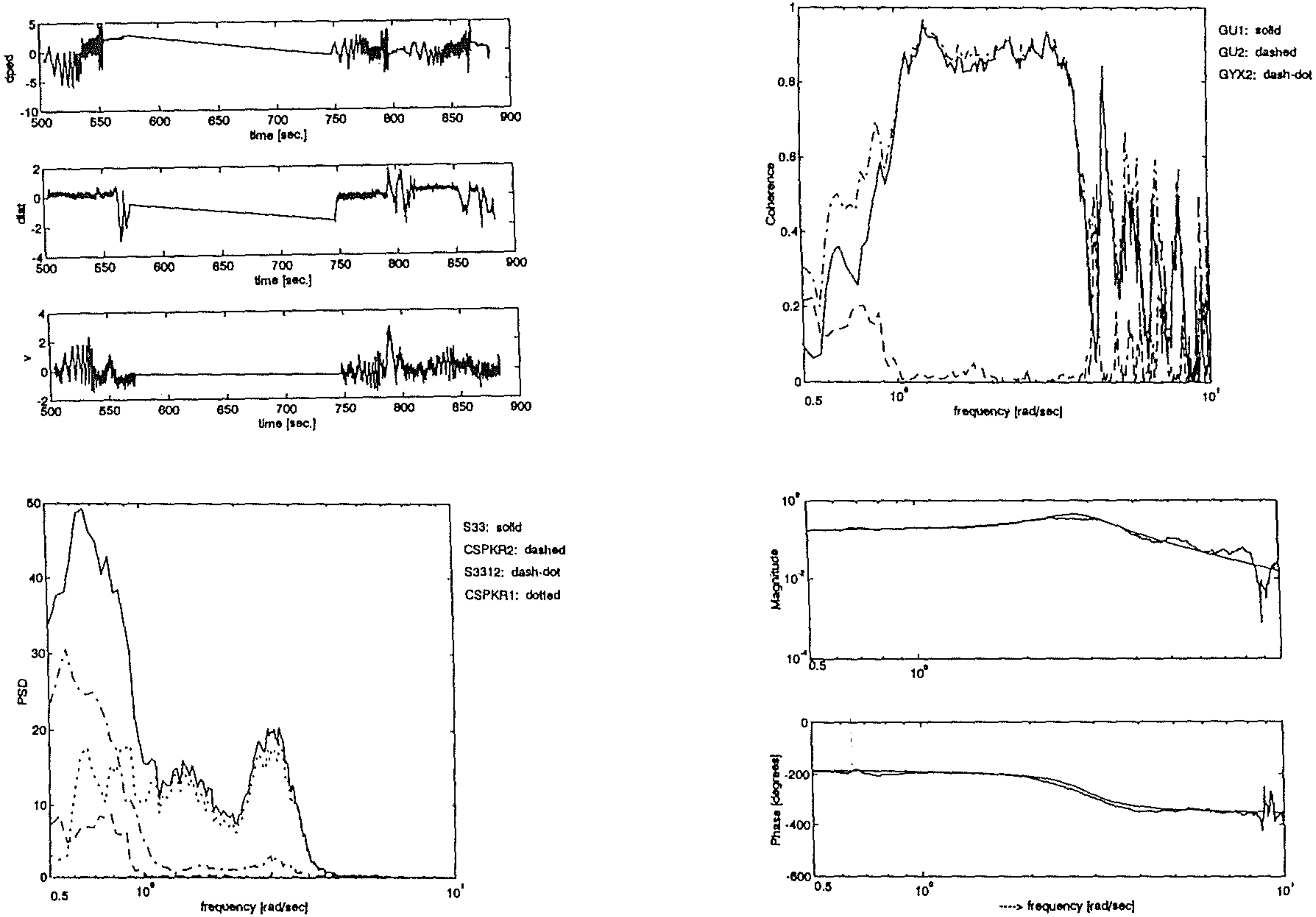


Fig 7: Comparison of BO-105 flight data and identified frequency response - dped to v

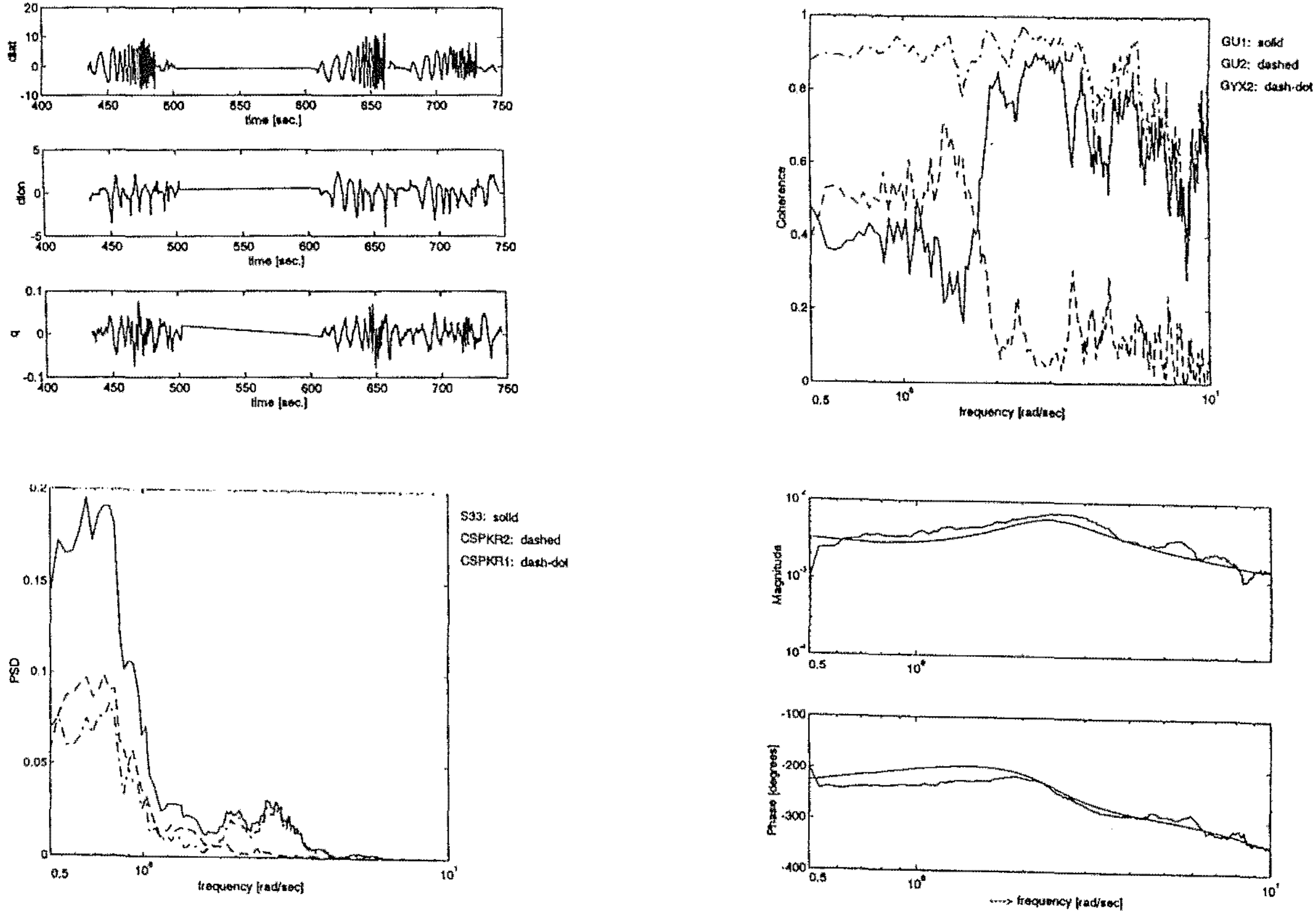


Fig 8: Comparison of BO-105 flight data and identified frequency response - dlat to q

Mode of motion	AFDD *	CERT	DLR	Glagow Univ.	NAE	NLR	TUD
Phugoid Osci.	[-0.36,0.30]	[-0.17,0.32]	[-0.15,0.33]	[-0.10,0.35]	[-0.14,0.33]	[-0.07,0.33]	[-0.4893,0.6741]
Dutch Roll osci	[0.22,2.60]	[0.13,2.51]	[0.14,2.50]	[0.16,2.27]	[0.13,2.58]	[0.17,2.17]	[0.17,2.55]
Roll mode	8.32	[0.99,2.89]*	8.49	5.12	8.47	2.38	6.9
Aperiodic pitch 1	6.04	-	4.36	1.98	4.38	1.37	4.63
Aperiodic pitch 2	0.49	0.66	0.60	0.64	0.63	0.71	0.011
Lead lag	[0.0421,15.8]	-	-	-	-	-	[0.03,15.72]
Rotor flap	[0.509,13.7]	-	-	-	-	-	[0.717,14.98]

* In this case aperiodic roll mode and fast pitch mode combine into an oscillory mode.

Table 1; BO-105 identification results: Time constants, damping ratios and undamped natural frequencies

Short hand notation

$[\zeta\ \omega_n]$ represents $s^2 + 2\zeta\omega_n s + \omega_n^2$

$(\frac{1}{\tau})$ represents $s + \frac{1}{\tau}$

Control	AFDD	CERT	DLR	Glasgow	NAE*	NLR*	TUD
Longitudinal	0.113	0.0	0.1	0.044	0.010	0.1	0.1296
Lateral	0.062	0.0	0.060	0.074	0.060	0.060	0.0310
Pedal	0.044	0.0	0.040	0.0	0.040	0.040	0.0535
Collective	0.168	0.0	0.040	0.102	0.040	0.040	-

Table 2: Time delay in seconds