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The French Air Academy
Salon de Provence – France

Moffett Field, CA

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The main rotor is a five blade fully articulated rotor, equipped with elastomeric bearings for the flapping motions, lead-lag and pitch change articulations.

The tail rotor is a four blade fully articulated rotor, equipped with elastomeric bearings that allow flapping, lead-lag and feathering movements.

The main characteristics of the helicopter are presented below in Table 1.

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The THALES flight dynamics model used for this case uuu(y) 67 T (o) fotye CmfES

Applications can range from identifying deficiencies in all axes

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The identified model parameters and associated Cramer Rao bounds and Insensitivities are given in Table 2 and Table 3.

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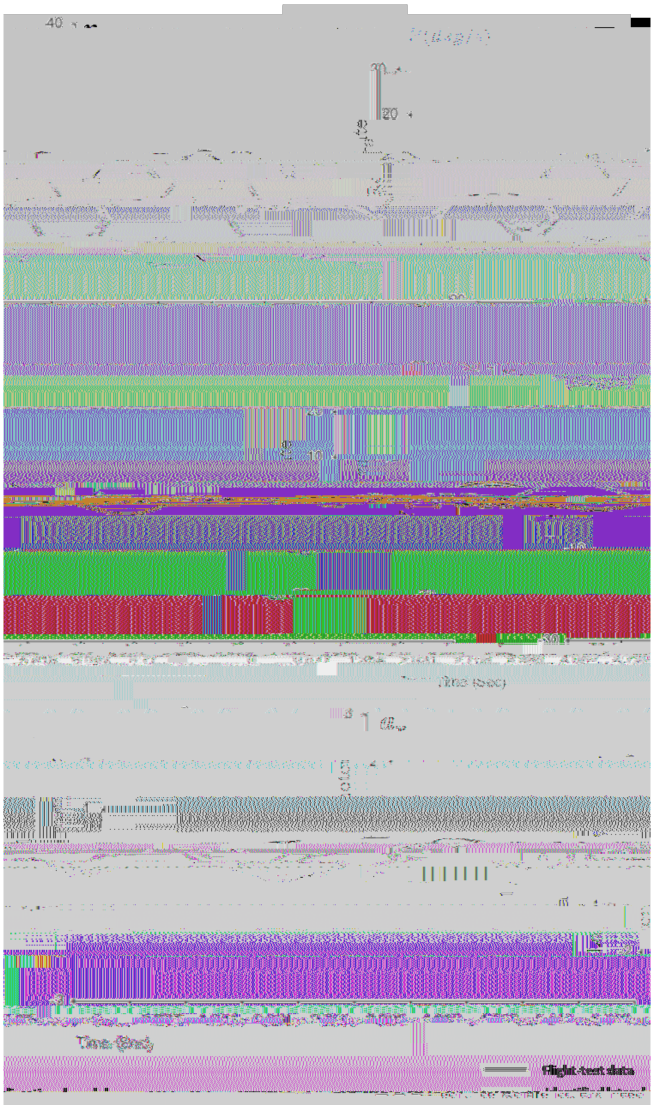
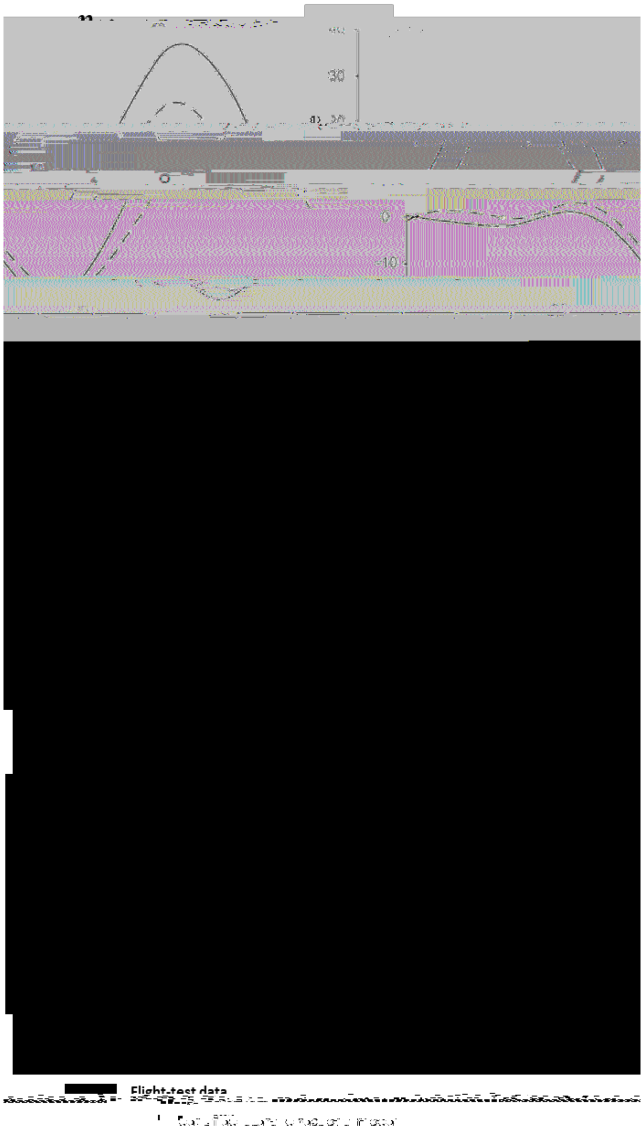
Eigenvalues $(\frac{rad}{sec})$	Mode
[illegible]	[illegible]
[illegible]	[illegible]
$\zeta = 0.3594$, $\omega = $ [illegible]	Dutch Roll
[illegible]	[illegible]

The eigenvalues for the identified model are given in Table 5. The Dutch roll is lightly damped and close in frequency to the stable aperiodic roll mode. The spiral mode is at low frequency and is slightly unstable.

Finally, the model is verified in the time domain as shown for a lateral stick (Figure 9) and a pedal input (Figure 10). Both time domain verification results show good predictive capability for large on-axis amplitude responses (30-40 deg/sec).

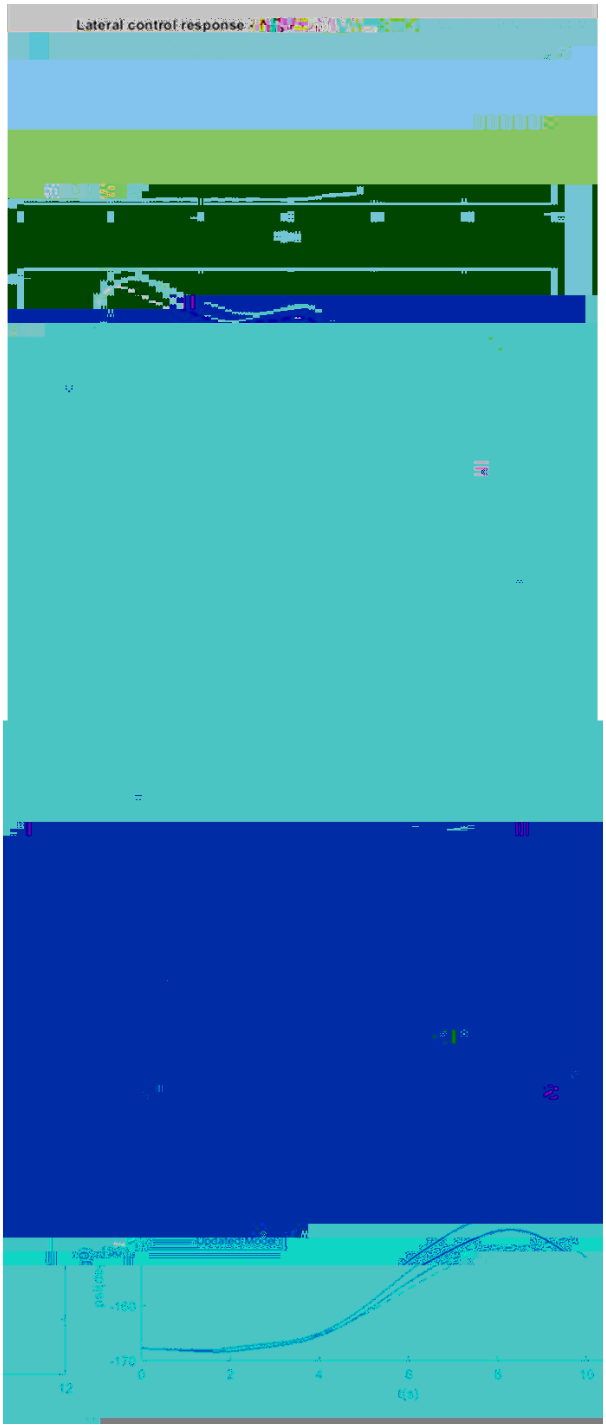




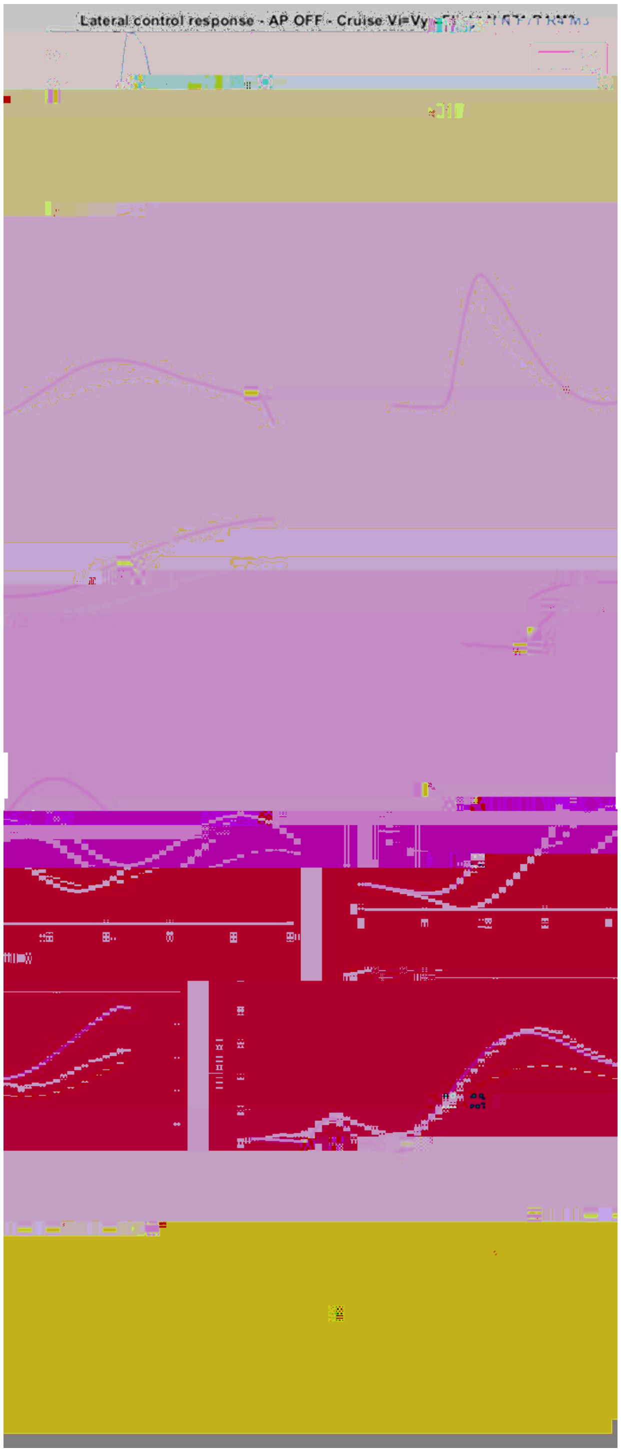
Corrective terms were calculated on roll and yaw moments (÷*L* and ÷*N*) and on lateral force (÷*Y*) and added to nonlinear forces and moments following the approach presented in equations EQ.1 and EQ.2. Table 6 presents the comparison of stability and control derivatives from system identification and physics based model linearization.

Z_w	
Y_v	0.02552
Y_p	0
Y_r	0.9209
L_v	−0.01449
L_p	−1.214
L_r	1.563
N_v	


Lateral control response - AP OFF - Cruise V


Lateral control response
-160
-170
0
2
4
6
8
10
t(s)


Lateral control response - AP OFF - Cruise Vi=Vy


Lateral control response - AP OFF - Cruise Vi=Vy

The lateral-directional oscillation (LDO) mode is shown in Table 8. The eigenvalues for the baseline model and the

Regarding the derivatives used for force and moment increments calculation the following model improvements were pointed out for further analysis:

Rotor flap hinge characteristics

The hub capacity to deliver rotor bending moment to the fuselage is mostly dependent on the flap hinge characteristics. The discrepancy observed in the L_p derivative could be a consequence of inaccurate values of the following parameters:

- Flap hinge offset
- Flap articulation stiffness and damping

Fuselage inertia,

In many cases simulator manufacturer doesn't have the accurate inertia of the fuselage. When insufficiently estimated, this parameter can impact the fuselage short term angular responses.

Main rotor interaction on Tail rotor

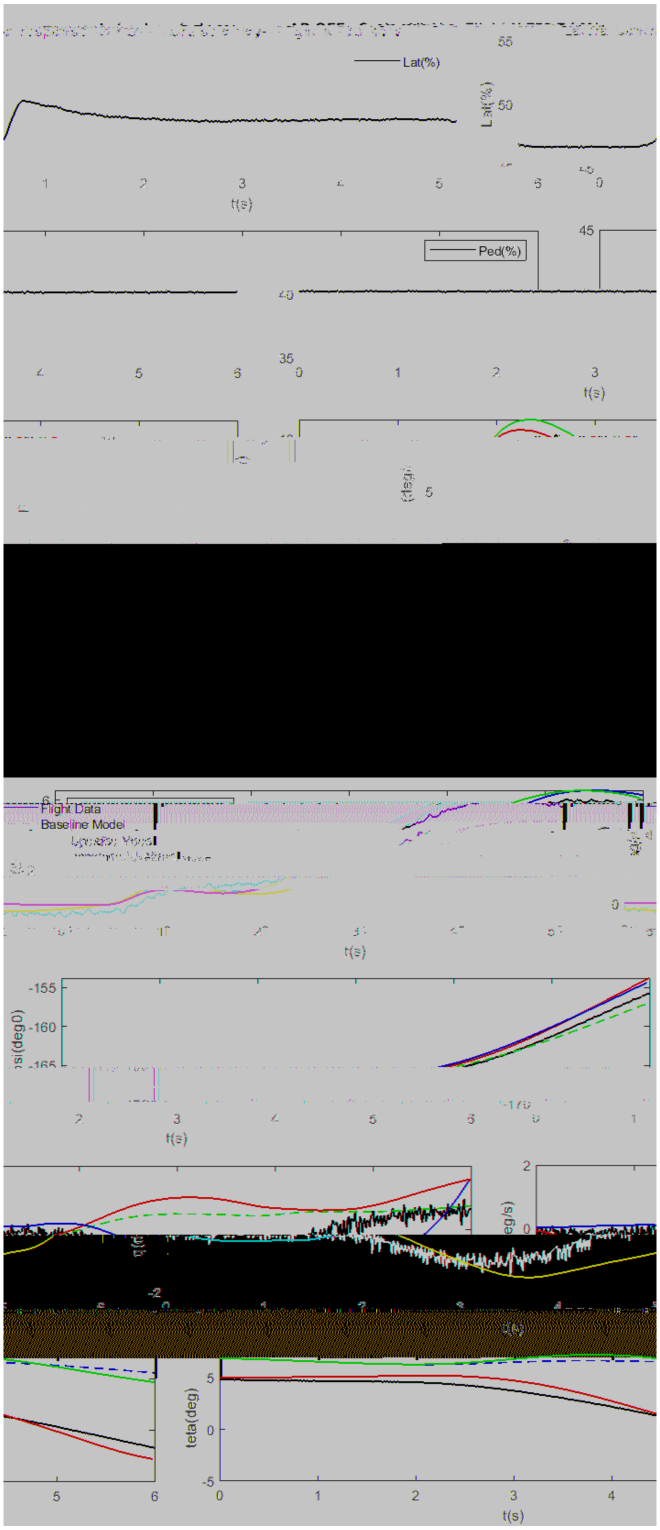
Tail rotor thrust is the primary parameter impacting yaw axis dynamics through the derivatives N_v, N_r. The efficiency of the tail rotor and associated stability derivatives N_v, N_r are significantly affected in forward fight by the interference with the shed wake of the main rotor.

In this case-study, many of the potential shortfalls identified above are due to inaccurate or lacking helicopter intrinsic data such as the flap hinge characteristics (offset, stiffness and damping) or the fuselage inertia. As candidate improvement parameters, they can be tuned, either manually or in a gradient-based iterative process, in order to improve the fidelity with FT data. As these parameters are supposed to be constant over the flight envelope, it's important to tune them at different flight speeds.

Under the scope of work of AVT-296, the physics based-model tuning of the AW139 to resolve the potential deficiencies identified earlier were investigated. Figure 16 presents the results for one flight case. The improved nonlinear model is in green. The tuning also included coupling with pitch axis. The model renovated with force and moment increments (from previous section results) is also presented in blue for comparison. Comparisons of the improved nonlinear model with flight data (in black) show a good matching in the 3 angular responses.

Further work is needed to assess and improve the physics-based model fidelity at other flight conditions. As stated before, this work focused only on system ID as renovated based on a single flight condition, whereas a full Level D simulation validation and update study will require model renovation based on system ID at several flight speeds.

So, the renovation improvements of the full flight envelope model will require system ID results at several flight conditions across the flight envelope (typical 4 flight conditions at low altitude and 4 flight conditions at medium altitudes; see Tischler and Remple, Ref. 4). However, the potential brought by the renovation method based on force and moment increments can greatly contribute to improve the first principle physics-modelling of the nonlinear flight simulation.



As stated earlier, the objective of this case-study was to investigate whether the existing QTG flight data could be used to extract some essential flight dynamics data and use them to renovate/improve the physics-based model.

The approach comprised 3 steps:

1. Investigate the applicability of using QTG flight test data for the use of System Identification methods to estimate stability and control derivatives (wherein, frequency sweep tests are the ideal flight-test inputs).

2. Apply the renovation method based on force and moment increments, first to improve the model fidelity, second to identify physics-based model shortfalls and improvement

3. Apply some of the improvement axes to the physics-based model

Regarding System Identification, frequency sweep tests are particularly well adapted to this purpose and have become, over years, standard tests for identification, complemented by time domain tests for model verification (Tischler and Remple, Ref. 4). Therefore, using QTG flight data for stability and control derivatives estimation could appear as a “step back” from frequency sweep testing. However, these QTG tests are commonly used during simulators’ certification development process. Furthermore, the realization of frequency sweep flight tests remains an obstacle for data package providers due to the additional flight test costs and increased accuracy of required instrumentation. Moreover, these tests need to be fully handled before becoming a part of simulators’ development process, and in general, require additional specialized test manoeuvres and special knowledge by rotorcraft system ID subject matter experts (SMEs). This means time and investment. Therefore, some manufacturers usually remain quite conservative in resorting to SID.

The case-study on AW139 QTG flights provides interesting thoughts to this discussion. It was found that applying frequency domain identification as developed by Tischler and Remple (Ref. 4) can provide with good ID fidelity and a set of extracted derivatives capturing some physical aspect of the flight dynamics. The exercise showed that roll damping (L_p), roll coupling to yaw (L_r) and yaw damping (N_r) could be identified with good fidelity. It comes out from this investigation that, even if the authors preach in favour of extensively developing dedicated SID flight tests in this process, undeniably the exercise shows that a solid approach in System Identification as developed in CIFER software suite can help capture some of the helicopter dynamics, even with QTG data not ideally suited to this purpose.

Regarding the renovation technique based on deltas of force and moment, it was applied successfully to the case-study. The study showed that it was possible to select a set of relevant derivatives for the case studied (lateral-directional dynamics). The direct addition of these force and moment increments demonstrated real model enhancement when matching with flight data. The Dutch-Roll characteristics prediction in terms of frequency and damping was also improved in comparison with SID results.

Moreover, the analysis of the derivatives helped identify

3. Force and moments increments are usually used by simulator manufacturers during their model certification process and determined using ad-hoc methods. However, the system ID-based method as applied within the STO Research Task Group proposes a systematic and physically meaningful way to calculate the force and moment deltas.

4. The relevant derivatives used in the study-case fed a physics-based model analysis and helped identify several modelling gaps. Furthermore, the physics-based model

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