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System Identification to support and enhance Flight Testing

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A project proposal

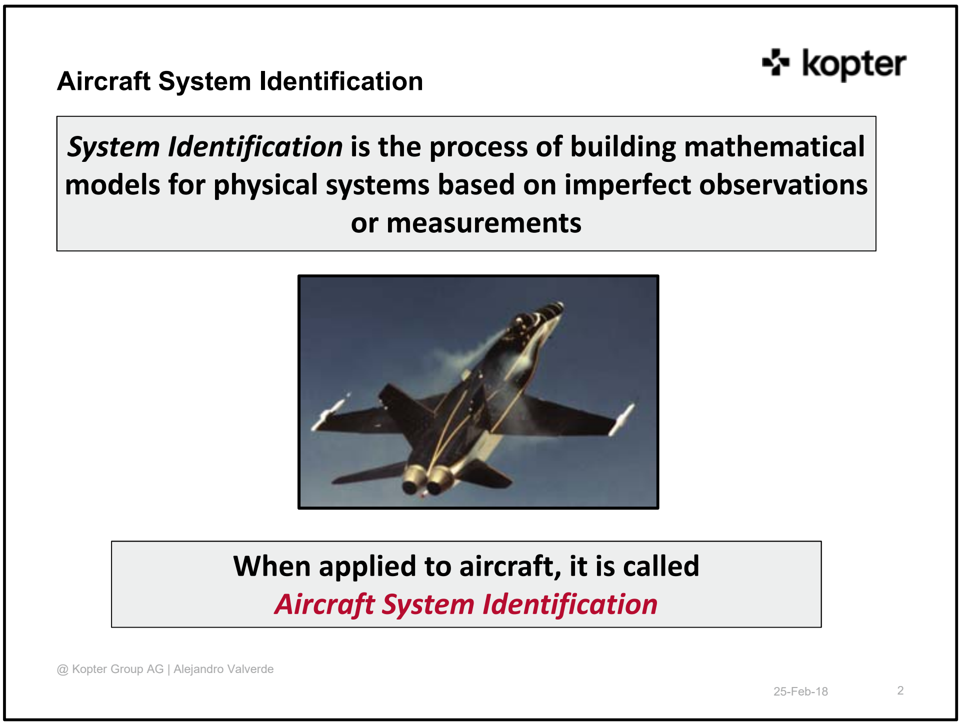
Alejandro Valverde

Hello everyone, my name is Alejandro Valverde and I have an idea. Idea which I would like to propose to you today.

For those of you already initiated in this topic, I would like to implement System ID techniques into the current Flight Testing methodology. I would do this in a:
- Cost effective,
- Efficient, and
- Accurate,

ways. And in this presentation, I will describe how I want to do this.

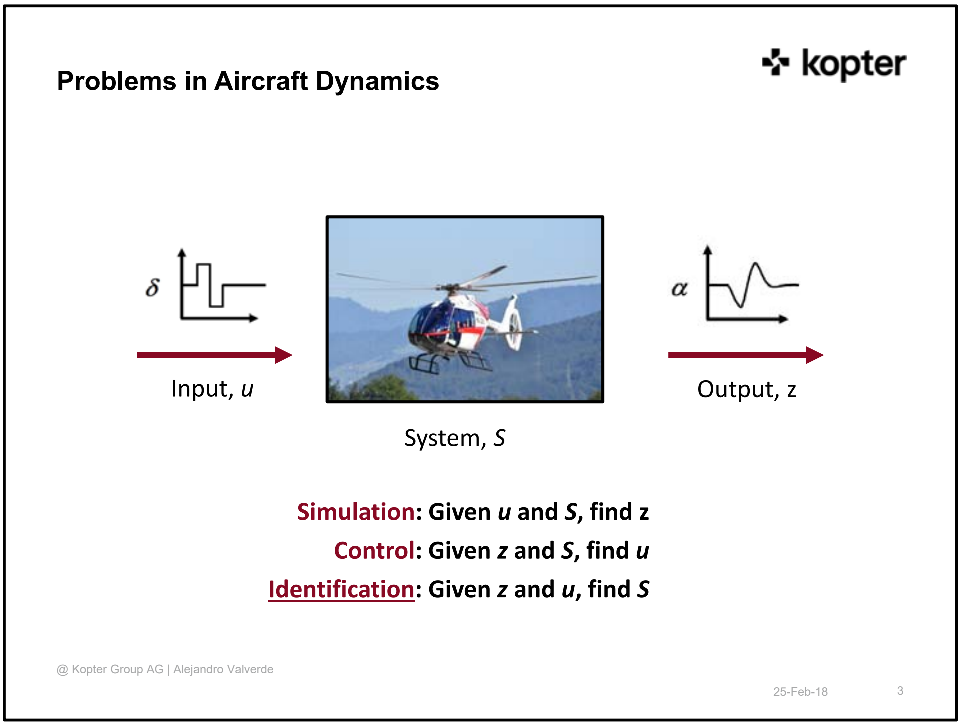
Now, for those of you not initiated in this topic…



One of the oldest and most fundamental of all human scientific pursuits is developing mathematical models for physical systems based on imperfect observations or measurements. This activity is known as system identification. When applied to aircraft, this is known as system identification.

And this is in fact one of the reasons why I am so interested in this topic, This discipline is fairly unknown in the aerospace industry, but it is in fact something that scientists and engineers have been doing for hundreds of years.

I like to recall know the contribution to human progress made by Johannes Kepler when, in 1609, he published the book *Astronomia nova* which presented a mathematical model that describe the motion of the planets in the Solar System. For this, he collaborated with the Swedish Tycho Brahe, who provided him with precise data of planets position in the sky. This was System Identification.



Now, in our company, we have already covered some of the classical problems of Aircraft Dynamics.

- Simulation: This is what the guys from Flight Physics do when they use FlightLab

- Control: This is what our pilot does in his brain.. Since, we don't have yet developed an autopilot, we don't need to worry too much about this point.

- Identification: Here is when we obtain a model for our helicopter, considering both the input and output to the model.

For Kepler, this box was ocuppaid by the solar universy, for us this is the SH09; but in fact it same. Well, in fact, poor Kepler's task was harder than us becaue he did have control over the inputs to the system and we do have.

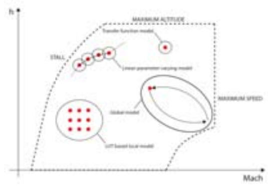
Applications of Aircraft System ID techniques

Aircraft System Identification offers a wide range of different applications, including:

Flight Simulator development

Picture of the flight simulator in the basement

Flight envelope expansion

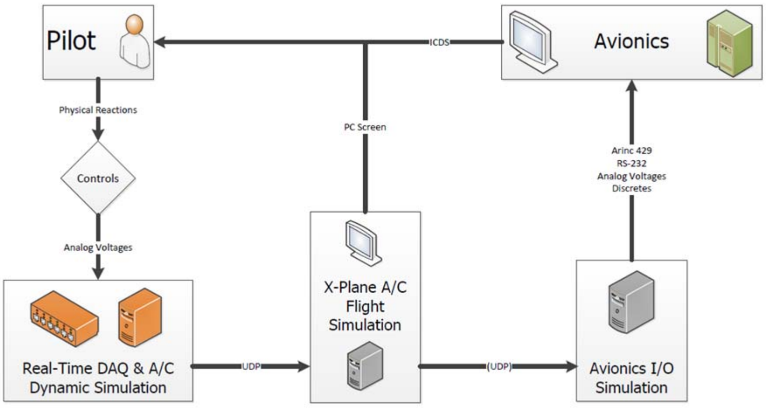


Evaluation of new aircraft

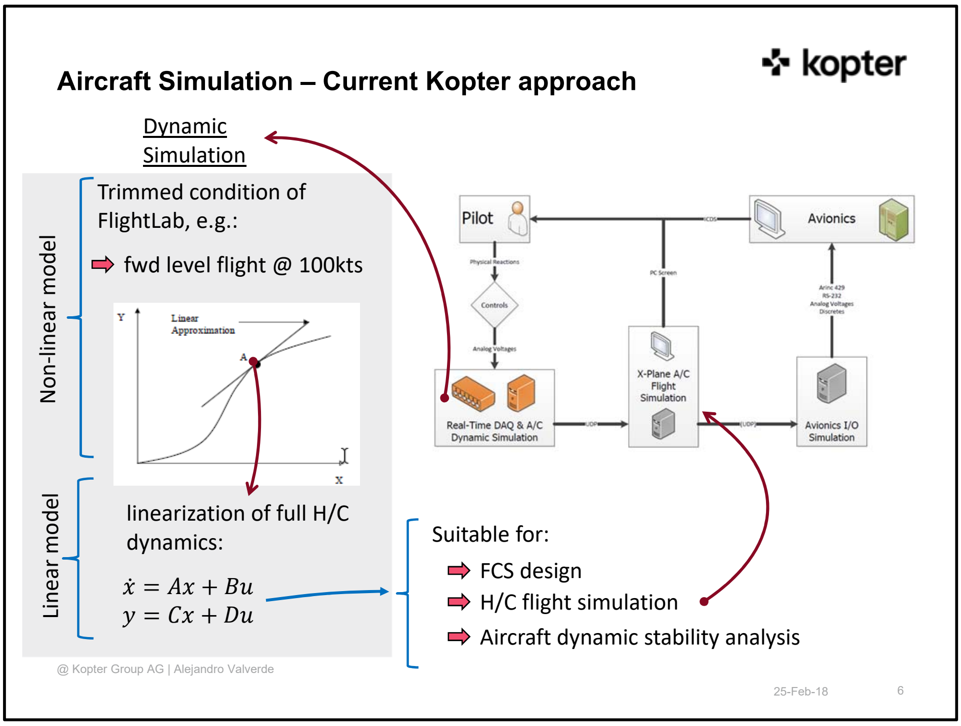
Handling Qualities assessment and enhancement

And many others…

Aircraft Simulation - Ongoing Kopter project



Extracted from Nicolas' MSc Thesis overview in collaboration with Kopter Avionics Dep.


Aircraft Simulation – Current Kopter approach
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Dynamic Simulation
Non-linear model
Trimmed condition of FlightLab, e.g.:
fwd level flight @ 100kts
Y
Linear Approximation
A
x
Linear model
linearization of full H/C dynamics:
$\dot{x} = Ax + Bu$
$y = Cx + Du$
Pilot
Avionics
Physical Reactions
Controls
Analog Voltages
PC Screen
Real-Time DAQ & A/C Dynamic Simulation
X-Plane A/C Flight Simulation
Avionics I/O Simulation
Suitable for:
FCS design
H/C flight simulation
Aircraft dynamic stability analysis
@ Kopter Group AG | Alejandro Valverde
25-Feb-18
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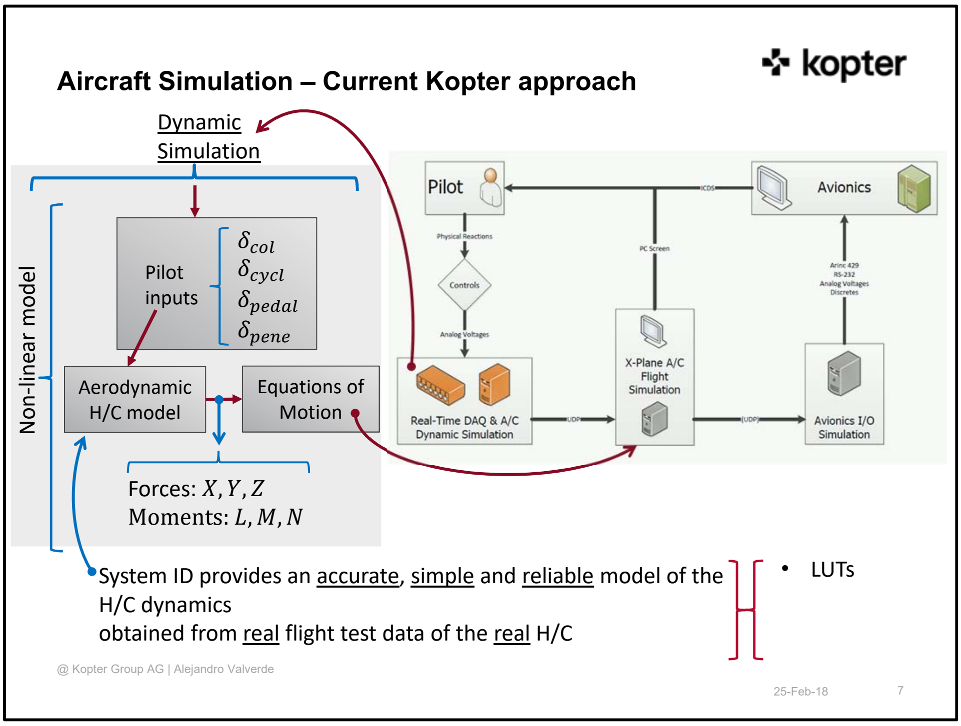

Accurate -> Because it's based on real flight data
Simple -> Does not require high computational power
Reliable -> Computed with

System ID R/C Model vs FlightLab

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H/C model from System ID

Advantages:
- High accuracy
- Validation -> instantaneous
- Non-linear flight dynamics
- Transient flight conditions
- Real-time dynamic modelling

Drawbacks:
- Depend on flight test data availability

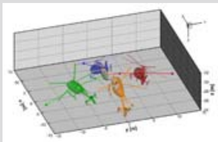
Best use: Dynamic model of the real H/C

FlightLab H/C model

Advantages:
- Not dependency on flight test data

Drawbacks:
- Validation -> complicated
- Only linear flight dynamics

Best use: Loads prediction



How does it work?

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Forces and moments

$$\frac{d}{dt}(mV) = \sum F = F_{Aero} + F_{Thrust} + F_{Gravity}$$

$$\frac{d}{dt}(Iw) = \sum M = M_{Aero} + M_{Thrust}$$

F_{Aero}, M_{Aero}: Develop a model form from which parameters can be estimated using <u>flight test data</u>

for example, using Taylor series expansion

Pitching moment coefficient

$$C_m = \underbrace{C_{m_0}}_{\text{pitching moment bias}} + \underbrace{C_{m_\alpha}}_{\text{static stability}} \overbrace{\alpha}^{\text{H/C angle of attack}} + \underbrace{C_{m_q}}_{\text{dynamic stability (damping)}} \overbrace{q}^{\text{longitudinal angular velocity}} + \underbrace{C_{m_\delta}}_{\text{pitch control authority}} \overbrace{\delta}^{\text{pitch control input}} + \nu_m$$

How does it work?

Pitching moment model:

$$C_m = C_{m_0} + C_{m_\alpha}\alpha + C_{m_q}q + C_{m_\delta}\delta + \nu_m$$

$$\theta = \left[C_{m_0}, C_{m_\alpha}, C_{m_q}, C_{m_\delta} \right]'$$

Vector of regressors (parameters to be identified)

Observations z

y: Model output
θ: Regresors
X: Values of variables measured
z: Observations
ν: Noise of the measurement

Model:

$$\left\{ \begin{array}{l} y = \boldsymbol{X}\,\boldsymbol{\theta} \\ z = \boldsymbol{X}\,\boldsymbol{\theta} + \boldsymbol{\nu} \end{array} \right\}$$

two approaches

- Equation-Error → Solved in one-shot linear algebra
  - Simple
  - In flight on fly estimations
- Output-Error → Solved with iterative nonlinear optimization
  - Any nonlinear system dynamics
  - Machine learning techniques

Tools – SIDPAC software

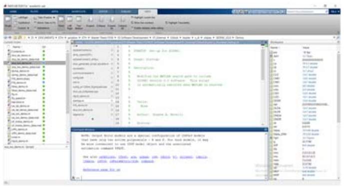
- Already available
- No development time needed
- Proven industry suitable software
- Further ways:
  - Python implementation

AIAA-2002-4704

System IDentification Programs for AirCraft (SIDPAC)

Eugene A. Morelli
NASA Langley Research Center
Hampton, VA

AIAA Atmospheric Flight Mechanics Conference
August 5-8, 2002 / Monterey, CA

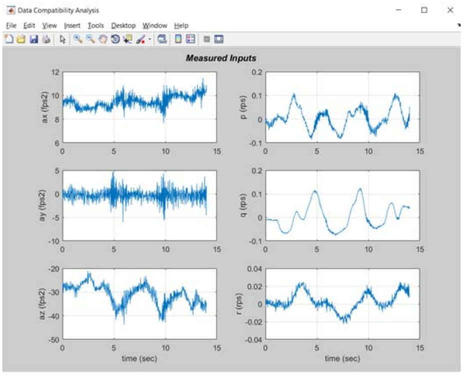


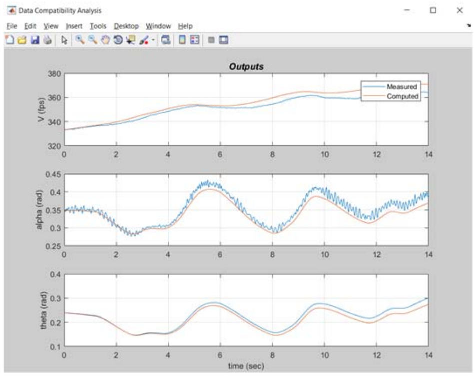
SIDPAC is a collection of over 350 programs that implement a wide variety of state-of-the-art methods for aircraft system identification

SIDPAC programs are implemented as MATLAB® M-files, and have been thoroughly tested and successfully applied to real data

SIDPAC is used at more than 80 organization worldwide to solve aircraft system identification problems

Tools – SIDPAC software





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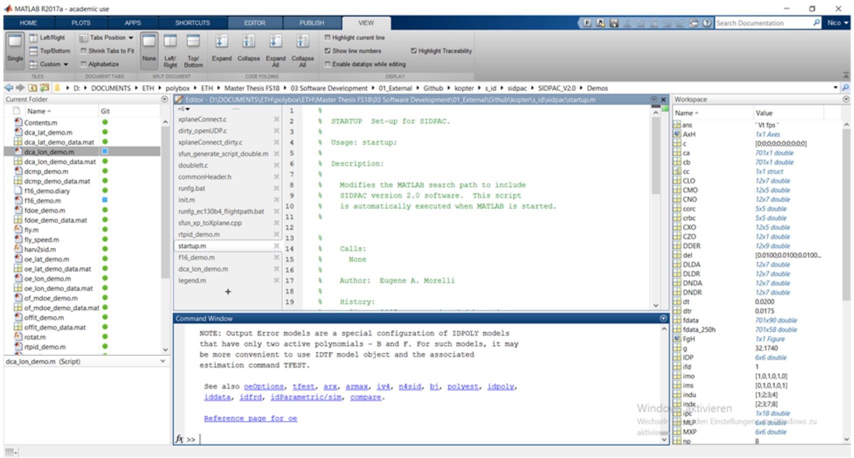
MATLAB R2017a - academic use
HOME
PLOTS
APPS
SHORTCUTS
EDITOR
PUBLISH
VIEW
Highlight current line
Show line numbers
Highlight Traceability
Enable datatips while editing
Editor - D:\DOCUMENTS\ETH\polybox\ETH\Master Thesis FS18\03 Software Development\01_External\Github\kopter\s_id\sidpac\startup.m
xplaneConnect.c
dirty_openUDP.c
xplaneConnect_dirty.c
sfun_generate_script_double.m
doubleIt.c
commonHeader.h
runfg.bat
init.m
runfg_ec130b4_flightpath.bat
sfun_xp_toXplane.cpp
rtpid_demo.m
startup.m
f16_demo.m
dca_lon_demo.m
legend.m
% STARTUP Set-up for SIDPAC.
% Usage: startup;
% Description:
% Modifies the MATLAB search path to include
% SIDPAC version 2.0 software. This script
% is automatically executed when MATLAB is started.
% Calls:
% None
% Author: Eugene A. Morelli
% History:
Command Window
NOTE: Output Error models are a special configuration of IDPOLY models
that have only two active polynomials - B and F. For such models, it may
be more convenient to use IDTF model object and the associated
estimation command TFEST.
See also oeOptions, tfest, arx, armax, iv4, n4sid, bj, polyest, idpoly,
iddata, idfrd, idParametric/sim, compare.
Reference page for oe
Current Folder
Workspace

What would I need?

some accelerometers installed in P3, a part from the usual instrumentation… -> we already have this

A laptop

Some coffee

Why to introducing System ID into P3 test campaign?

- Sooner or later –> Every big helicopter manufacturer has SID implemented

- Assist P3 flight envelope expansion
- Provide a propor dynamic model of the H/C for the simulator
- Cost effective
- Surely it will be need for PS4 and further developments after TC

We have to do it now, we are ready now

- *System ID takes time and money – but not nearly as much as not doing it*

Eugene A. Morelli
NASA Langley Research Center Hampton

Why I can be the one doing this?

Young <-> Passion

I know what to do and how to do it

Kopter experience

Data analysis experience
- Python
- Matlab
- Data analysis and machine learning techniques
- …


SH09
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Thank you

Kopter Group AG
Binzstrasse 31
8620 Wetzikon
Switzerland

Registered Office
Flugplatzareal 10
8753 Mollis
Switzerland

E contact@koptergroup.com
T +41 44 552 33 33
koptergroup.com

References

- [1]: Aircraft System Identification. Theory and Practice.