CHALMERS

VIRTUAL DEMONSTRATOR PLATFORM FOR FUTURE PROPULSION TECHNOLOGY

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VIND PROJECT

GKN AEROSPACE

LUND UNIVERSITY

CHALMERS UNIVERSITY OF TECHNOLOGY

KTH VETENSKAP OCH KONST

- NFFP 7 project VIND
  - Virtual Integrated Demonstrator for Turbomachinery
  - Running 2018-2021

- Chalmers works on developing a scalable aircraft analysis platform for technology assessment

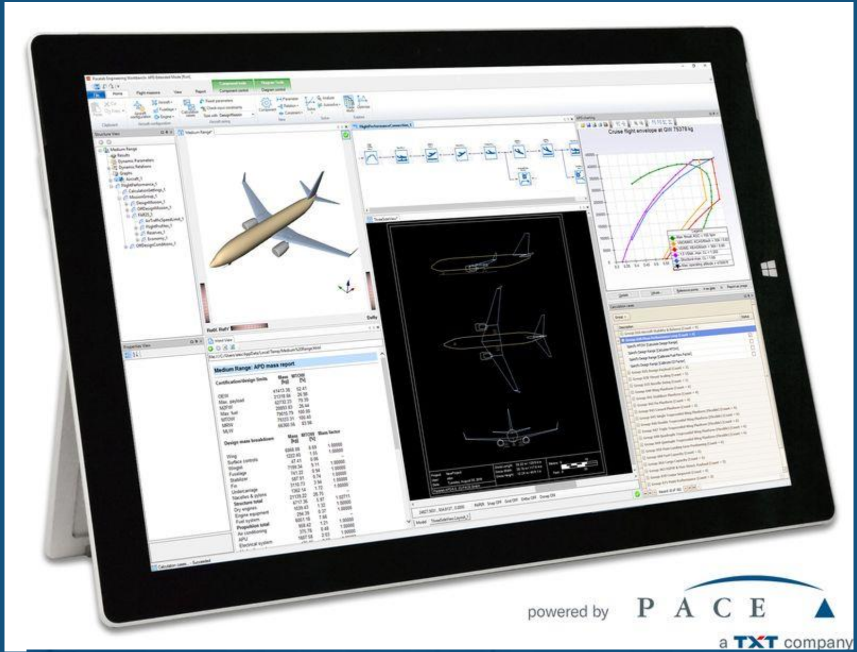
VIRTUAL DEMONSTRATOR PLATFORM

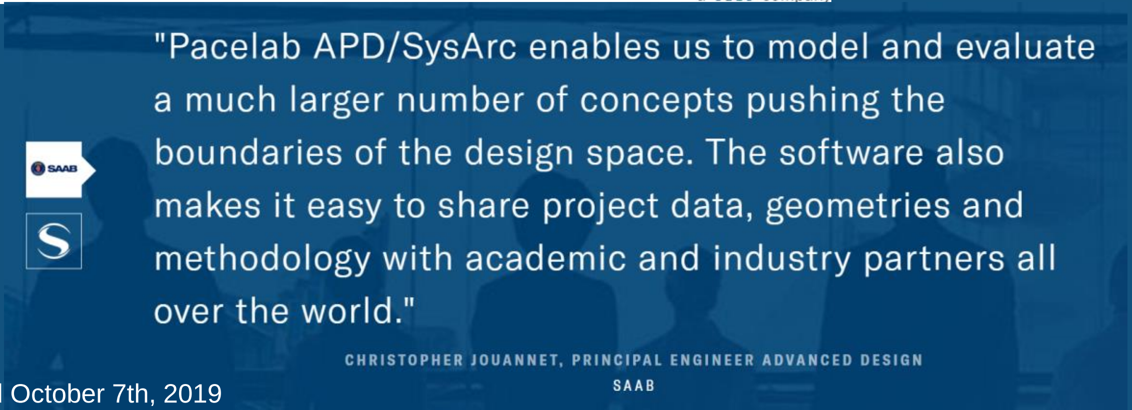
- Purpose
  - Allow evaluation of new propulsion technologies on aircraft design level
- Ambition
  - Scalable aircraft model (use commercial tool, APD)
  - Scalable propulsion system (use existing in-house Chalmers tool)
  - Weights & sizing (use existing in-house Chalmers tool)
  - Noise characteristics (develop in collaboration with KTH)
  - Allow optimization
  - Demonstrate capability by developing integrated models for compressor, generator and generator cooling technology

Aircraft modelling

Pacelab APD

- Commercial software for aircraft design
- Supplement with in-house methods (to be developed)





https://www.txtgroup.com/markets/solutions/pacelab-apd/, cited October 7th, 2019

AIRCRAFT INPUT

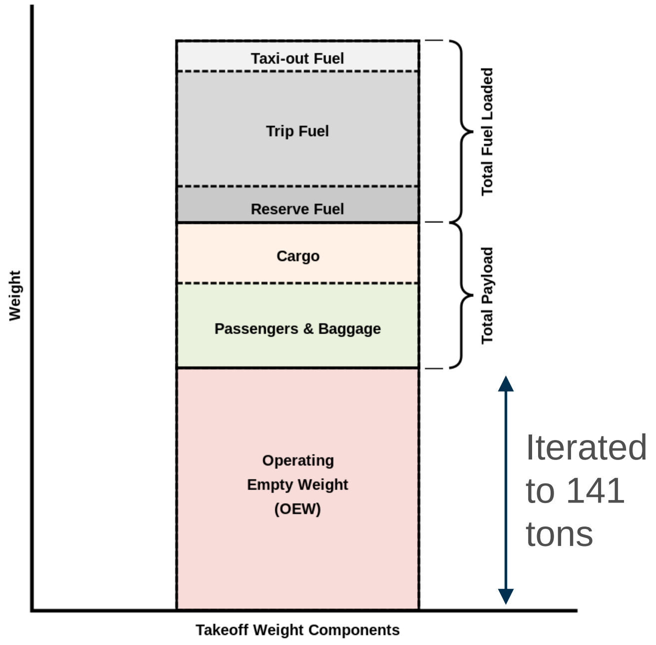
- Airbus A350-XWB Pacelab APD model.
- Design requirements:
  - Range 8100 NM
  - 325 PAX
  - Initial cruise at 35,000 ft
  - Climb to 35,000 ft in less than 25 min (TOC M0.84)
    - Air traffic control limits CAS = 250 kts up to 10,000 ft
    - After 10,000 ft climb at optimum CAS = 300 kts
  - Take of field length, 3200 m
  - Landing field length, 1600 m
  - Fuel reserves: 5% contingency fuel, 100NM diversion @20,000 ft, 30 min hold

AIRBUS A350-900
Specifications

Characteristics	
Wing loading	640.5 kg/m^2
PAX	48J + 277Y
Cruise Mach	0.85
Thrust	
Engine	2 Rolls-Royce XWB-84
Output/Flat Rating	2 x 84,200 lbf / ISA+15 C
Weights	**Kg**
Max Ramp Weight	280,900
Max TO Weight	280,000
Max Land. Weight	207,000
Max Zero Fuel Weight	195,000
OEW	141,000 (*calculated*)
Max Payload Structure	54,000
Max Fuel	113,000
Limits	
Ceiling certification	43,100 ft
Max operating Mach	0.89

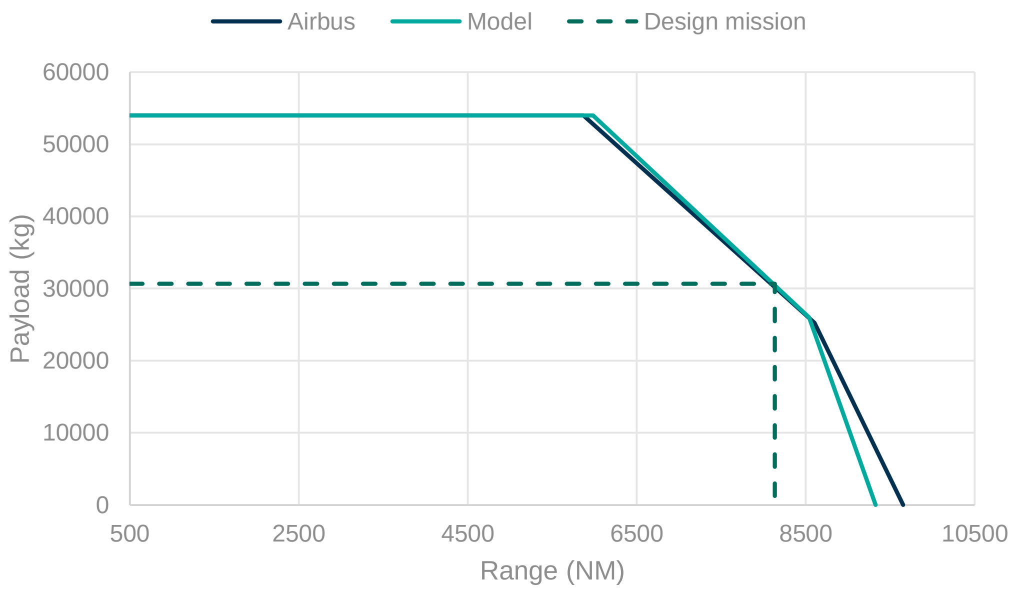
AIRCRAFT MODELLING

- Assumptions during matching:
  - Goal is to match the design mission range, while iterating on engine and aerodynamic performance.
  - Engine performance:
    - 15% improvement in SFC over original Trent engine[1]: 14 mg/Ns.
  - Overall Improved aerodynamics[2]:
    - Nacelle with higher portion of natural laminar flow.
    - Improved design with support of high fidelity CFD
    - Drop-nose device on inboard wing: low speed drag reduction
    - Adaptive Drop Hinge Flap: improved high lift efficiency, load alleviation functions and cruise efficiency improvement



[1] Jane's Aeroengines ISSUE 27, 2010
[2] A350 XWB Family and Technologies, Olivier Criou

VALIDATION



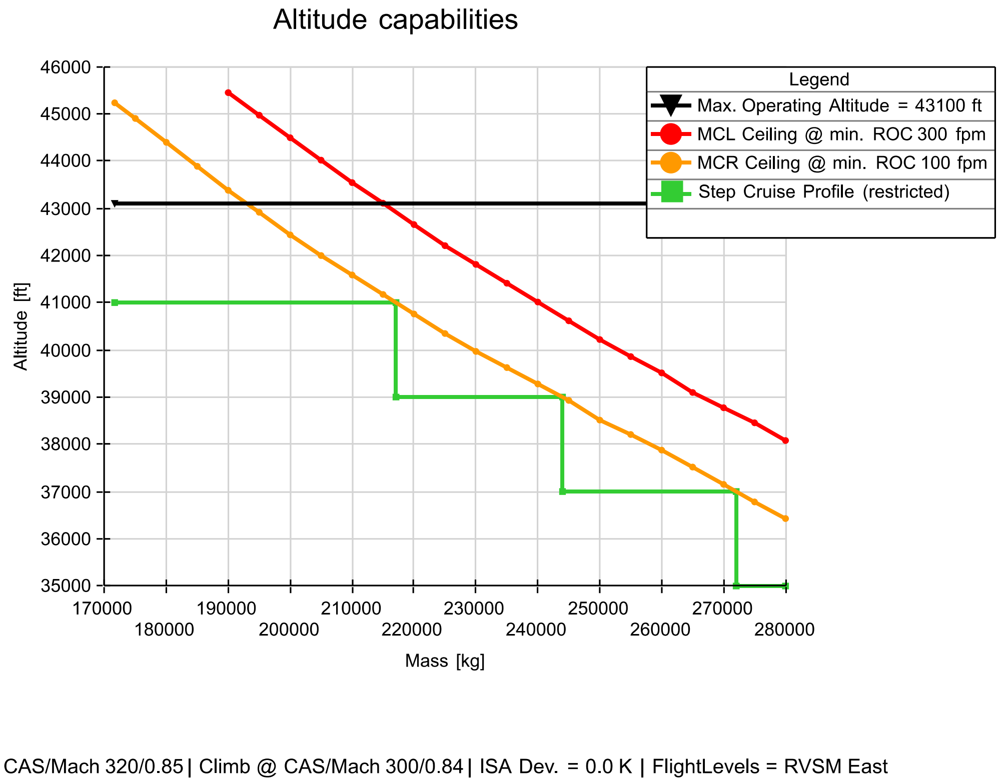
Known:
- Max. payload: 54,000 kg
- MTOW: 280,000 kg
- Fuel: 140,700 l
- Cruise Mach: 0.85

Unknown:
- Take-off, Climb, taxi, descent conditions
- Propulsion system matching
- OEW

Some validation against Jumbos (GKN tool) expected

AIRCRAFT ENGINE MATCHING

- Match engine propulsion system
- Update mission specification



RE-ENGINE WITH RM400 (A350 ~Y2035 VARIANT)

- RM400 data provided by GKN
- RM400 performance re-created in-house tool GESTPAN
- RM400 thrust requirements to match A350-XWB
  - SLS: 84,200 lbf
  - Max Climb, ISA @M0.84, 35,000 ft: 20,000 lbf
  - Max Cruise, ISA @M0.85, 35,000 ft: 17,000 lbf

- New engine deck generated by GESTPAN:
  - Thrust and fuel data input
    - code_MTO = 50
    - code_MCL = 40
    - code_cruise = 35
    - code_fuel = 0

Thrust file input:

Vary for each rating condition (50 – MTO,)

RC	ISA	MN	ALT	FN	FF
	K		ft	lbf	lb/h
50	0	0	0	22045.5	6294.5
50	0	0.0756	0	20279.1	6362.8
…					

Fuel file input:

Vary

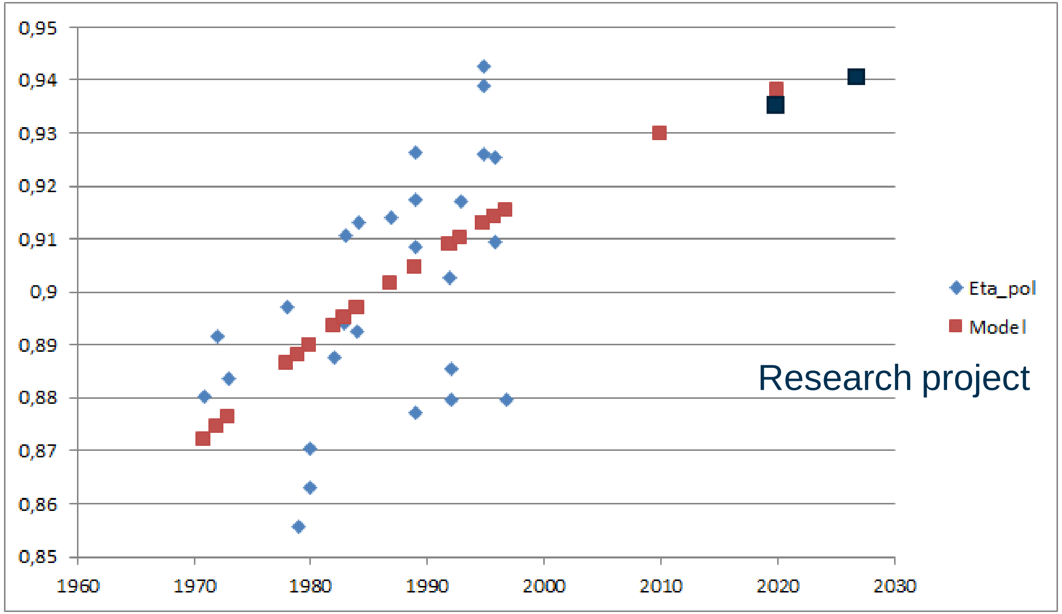
RC	ISA	MN	ALT	FN	FF
	K		ft	lbf	lb/h
0	0	0	0	22045.5	6294.5
0	0	0	0	17084	4936.3
0	0	0	0	14521.4	4130.4

Propulsion modelling

PROPULSION

- Trend parameters
  - Size & Reynolds
  - Cooling effects
  - Entry into service

- Grieb, Projektierung von TurboFliegtrieb-werke.



KEY PERFORMANCE DATA

- Multipoint match models for key efficiencies
- After first model has been decided:
  - Generate performance for aircraft mission
  - Could require iteration

Parameter (TOC)
η_{FAN}
$\eta_{FAN,\ inner}$
η_{IPC}
η_{HPC}
η_{HPT}
η_{LPT}
T40

ENGINE PERFORMANCE SIMULATION

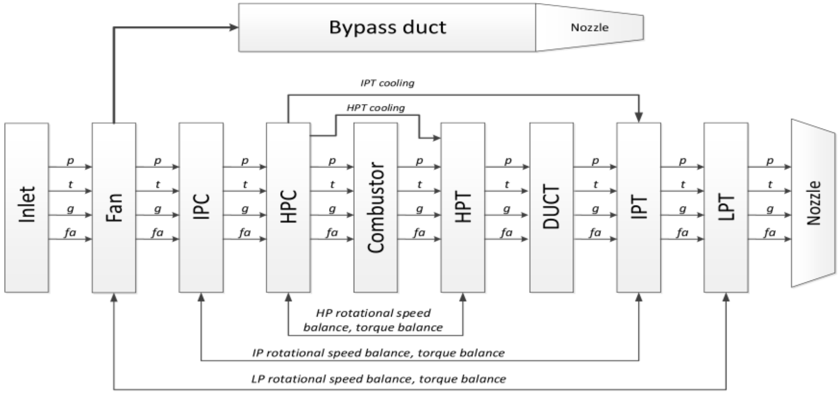
GESTPAN – General Stationary and Transient Propulsion Analysis

- Zero-dimensional aero-thermodynamic analysis employing discrete component maps
- Solves for the mass and energy balance between the various engine components
- Ability to simulate a wide range of aero-engines as well as industrial gas turbines

Image courtesy of CFM.

Key Capabilities

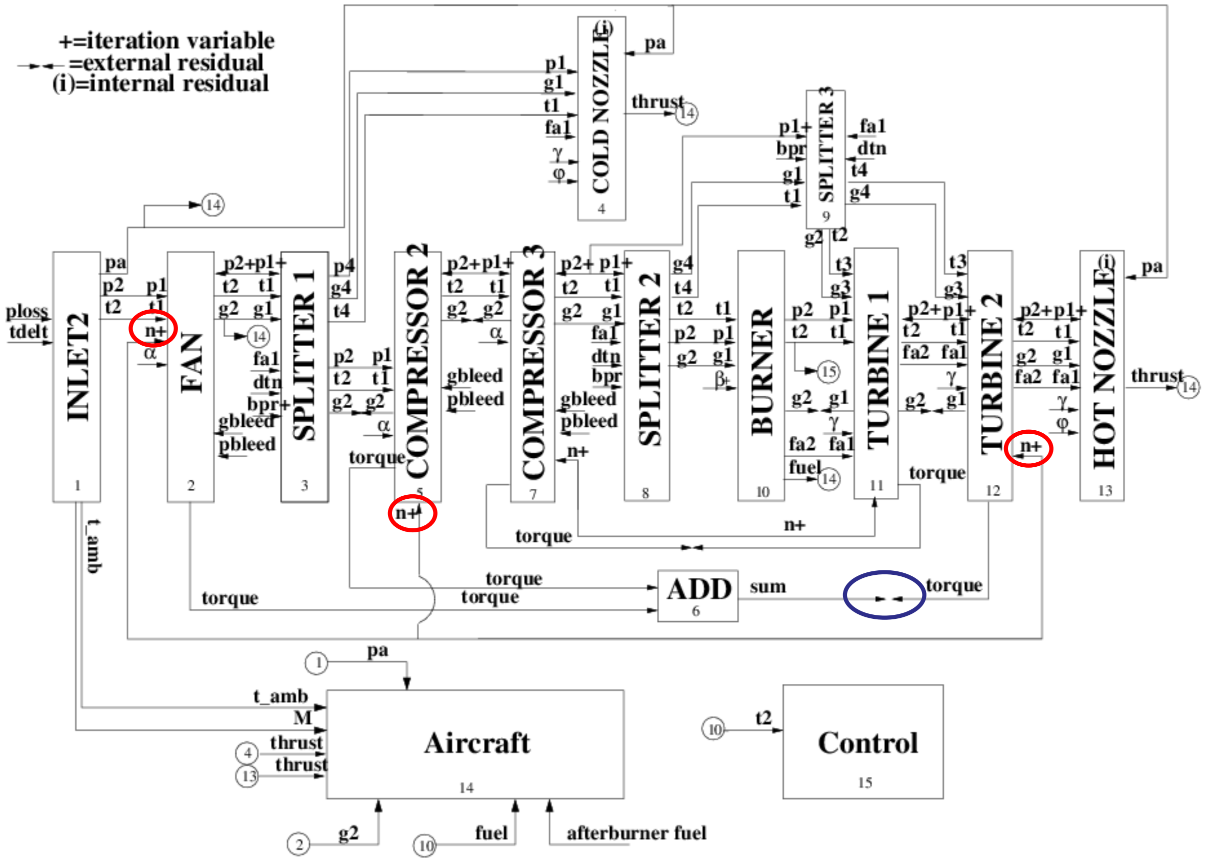
- Ability to introduce customised (user defined) component characteristics.
- Design, Off design and transient performance calculations



GESTPAN - Interconnected Engine Component Schematic of Turbofan

*Grönstedt, T., "Development of Methods for Analysis and Optimization of Complex Jet Engine Systems", PhD Thesis, Department of Thermo and Fluid Dynamics, Chalmers University of Technology, 2000.

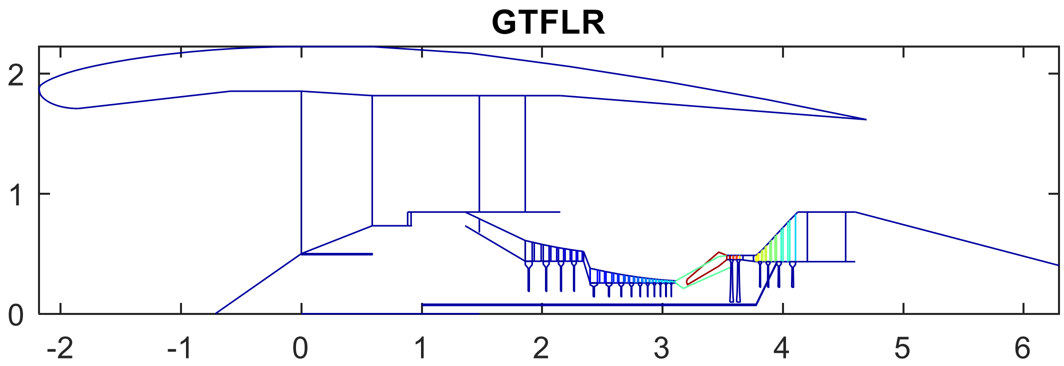
ALGEBRAIC SYSTEMS AND CAUSALITY



Propulsion conceptual design

WEIGHT AND DIMENSIONS PREDICTIONS

- Automatic sizing prediction
  - Multipoint design



- Dimensions based weight prediction

- Turbomachinery flow and blade speeds available

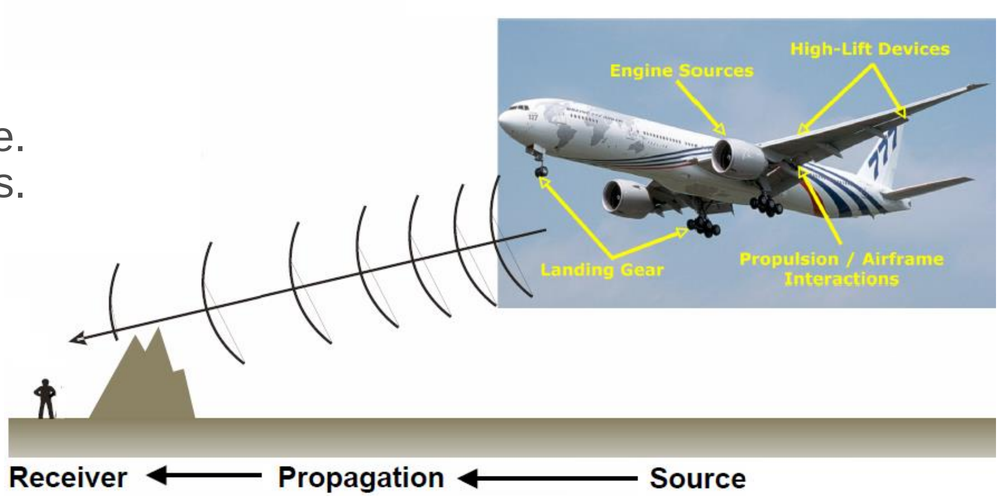
Noise

HOW TO ESTIMATE NOISE

1. Source modelling. Definition of a number of component models and estimates of noise
    - Fan, Lpc, Combustor, Turbine + Airframe (high lift devices, landing gear…)
    - Directivity and frequency dependence.

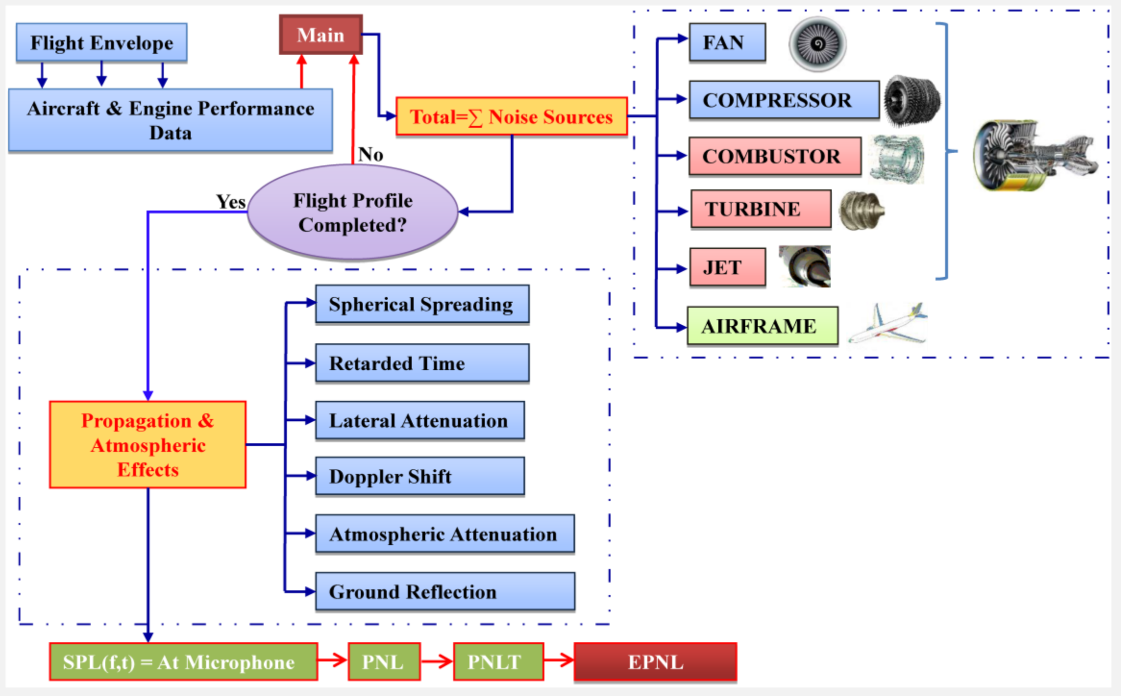
2. Trajectory definition. Retarded time. Propagation and atmospheric effects. Damping models. Spherical spreading.

3. Noise metrics at the receiver



SYSTEM LEVEL NOISE MODELLING

- Source terms then need to be evaluated at every point on the trajectory
- Then you need to match these points at the microphone.
- This requires pairing trajectory points in time.



- Noise level. Broadband term (Lateral point = sideline)

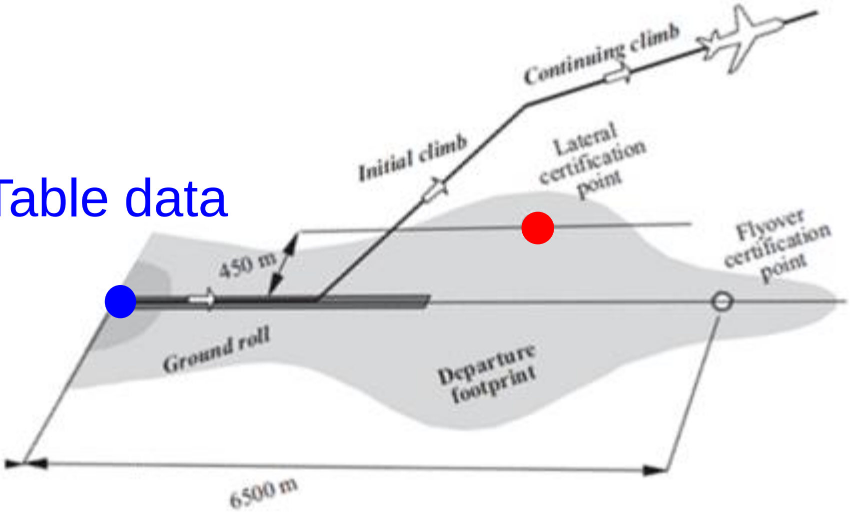
Interim Prediction Method for Fan and Compressor Source Noise

Marcus F. Heidmann

$$L_c = 20log_{10}\frac{\Delta T}{\Delta T_{ref}} + 10log_{10}\frac{\dot{m}_0}{\dot{m}_{ref}} + F_1[M_{tr}, M_{trD}] + F_3(\theta)$$

$$SPL(f) = L_c + F_4(\frac{f}{f_b})$$

Table data



$$f_b = blade\ passing\ frequency = n_{Blades} f$$

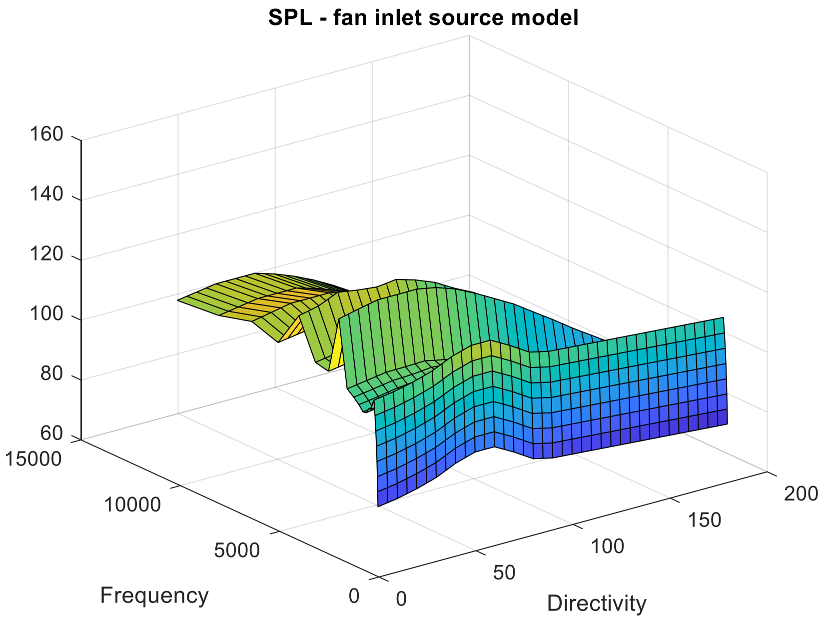
Variable (first point on runway)	Value
ΔT (varies in trajectory)	57.6 K
ΔT_{ref} (constant)	0.555
$\dot{m}_{ref}$ (constant)	0.4536
$\dot{m}_0$ (varies in trajectory)	396.1 kg/s
M_{tr} (varies in trajectory)	1.56
M_{trD} (constant)	1.71
n_{blades} (constant)	24

Note that f is the same as the rotational speed

Sample model – fan noise

- **Input:**
  - Temperature rise
  - Mass flow
  - tip Mach number in design point
  - tip Mach number in current point
  - number of rotors & stators
  - spacing

SPL(θ,f) **in each operating point**



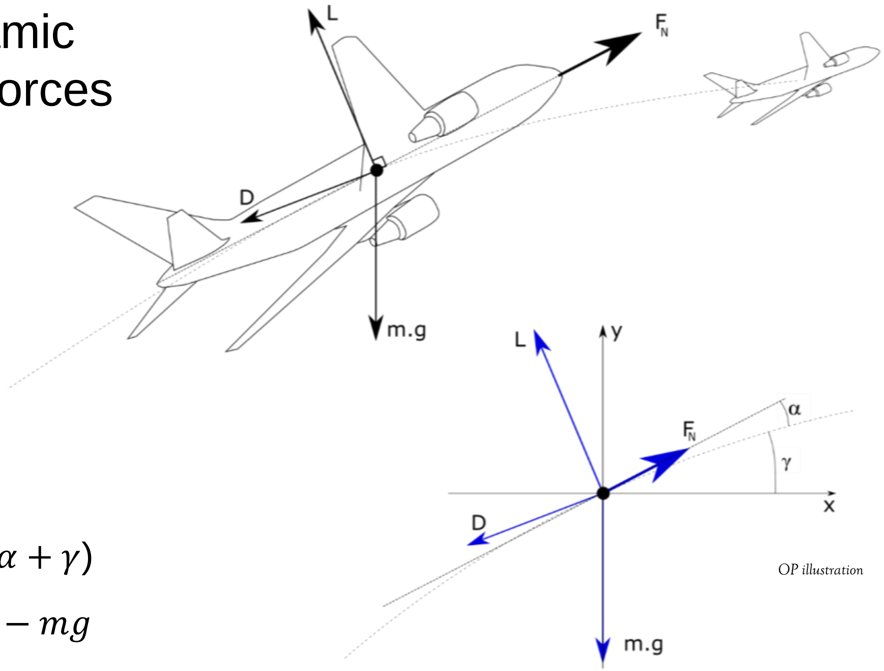
Aircraft performance and noise

- To build a simple dynamic aircraft model project forces in x- and y- direction

- Again we simplify by setting the engine orientation in the flight direction.

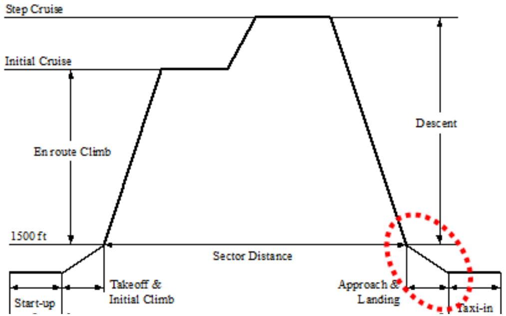
$$F_x = -L sin\gamma - D cos\gamma + F_N cos(\alpha + \gamma)$$

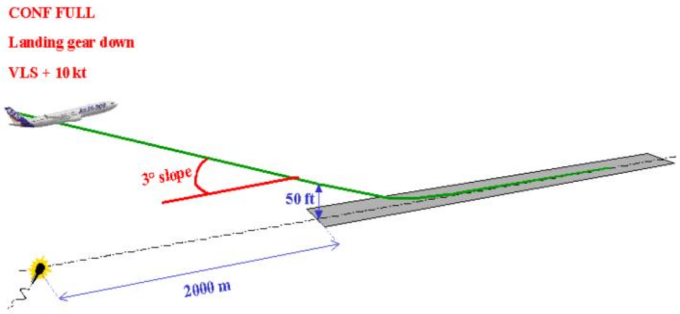
$$F_y = L cos\gamma - D sin\gamma + F_N sin(\alpha + \gamma) - mg$$

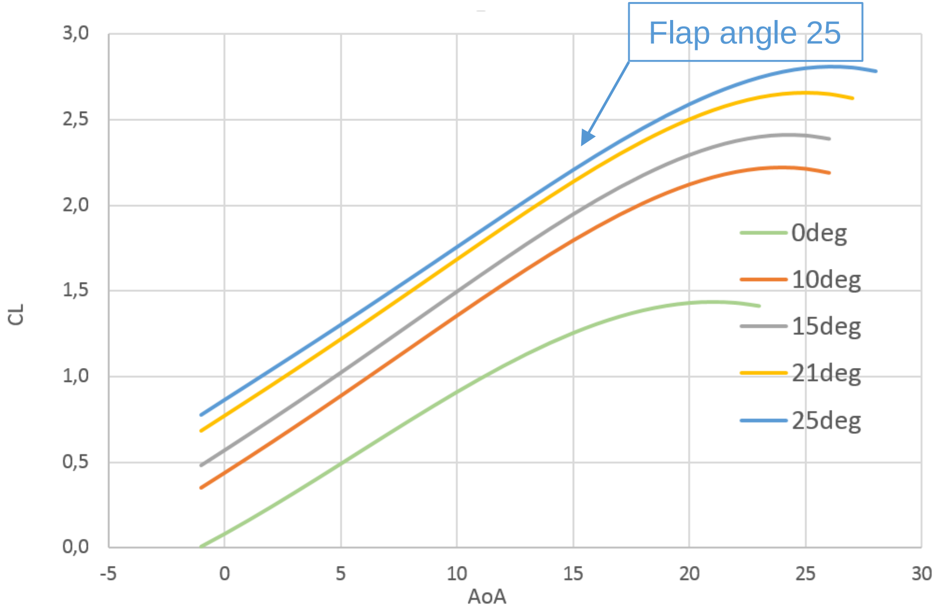


- Lift and drag are obtained from previously derived expressions.

During approach flap settings are changing







AoA = angle of attack = α

Landing gear is down

EPNL (Effective Perceived Noise Level)

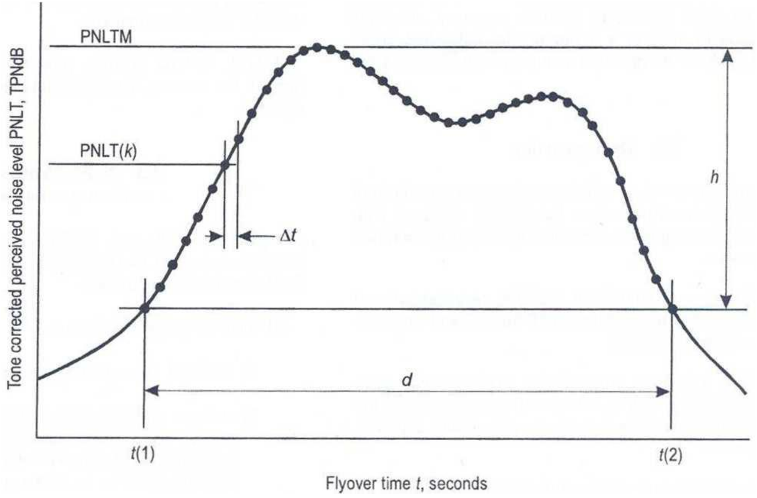
- EPNL is a measurement which includes the duration of noise an observer has to endure.
- The duration (D) is an integration in time based on the maximum sound heard during the time interval.
- The time interval (t(1) and t(2)) is chosen depending on the maximum noise level (PNLTM)

$$D = 10\log_{10}\left[\frac{1}{T}\int_{t(1)}^{t(2)} 10^{\frac{PNLT}{10}}dt\right] - PNLTM$$

$$D = 10\log_{10}\left[\frac{1}{T}\sum_{k=0}^{d/\Delta t} \Delta t \cdot 10^{\frac{PNLT}{10}}\right] - PNLTM$$

$$PNLTM = \max(PNLT)$$

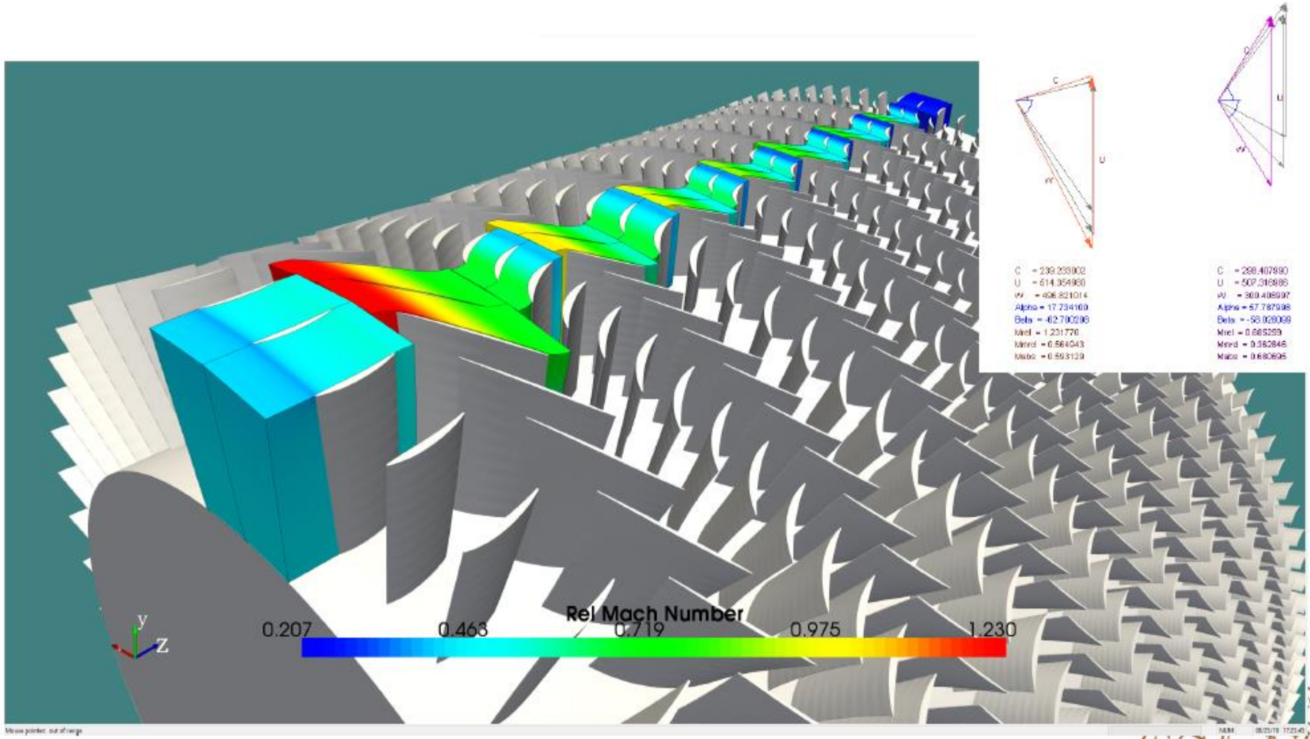
$$EPNL = D + PNLTM$$



Example of PNLT sampling during a flyover

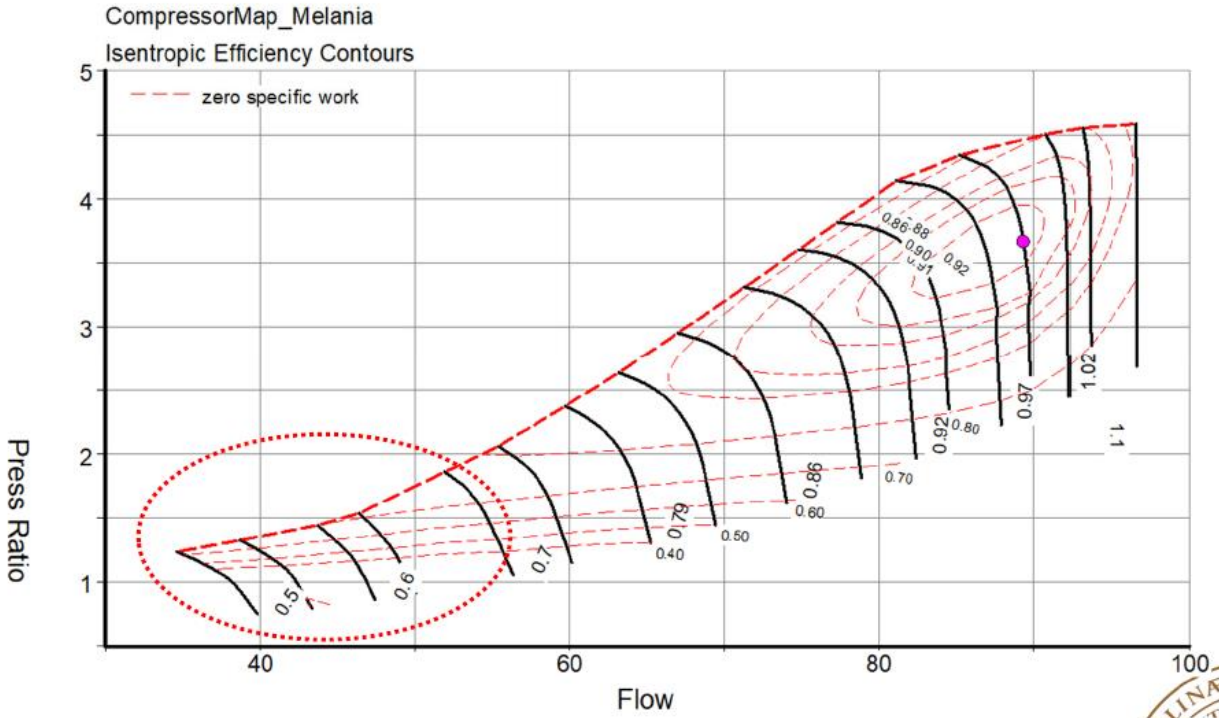
System level assessments

Component design – what is the system level influence?



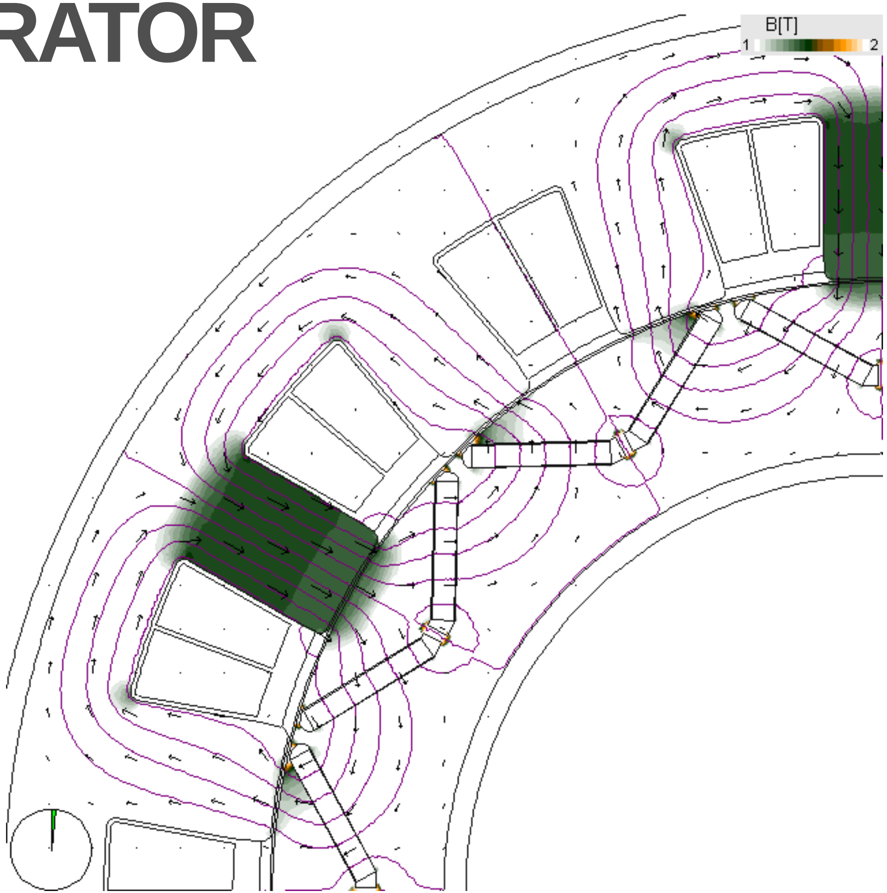
CHIC - Booster

- Fed back in system model to study stall margin and fuel burn benefits



INTEGRATION OF GENERATOR

- Engine conceptual design gives constraints on size
- Integration of generator cooling can be done using propulsion synergy
  - Secondary fluid heat rejection to bypass channel
- Go to I13, 11.30-12.00, to see **"Aerospace electric generator specification and selection – opportunities and challenges"**



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