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## **Improved 0D Sizing of High Speed Civil Transportation Aircrafts**

*Jean-Yves Andro<sup>1</sup>*

### **Abstract**

This paper aims at presenting an improved version of a MDAO (Multi-Disciplinary Analysis and Optimization) tool developed by ONERA in order to support the designer during the initial conceptual design phase of high-speed civil transportation aircrafts. This tool helps to evaluate the long-term sustainability of operative concepts by providing a 0D sizing (maximum take-off mass, fuel mass, dry mass, plan surface, volume, lift and thrust requirements, ticket price per passenger...) corresponding to a specific mission in terms of range (3000 to 18000 km), number of passengers (10 to 300), fuel (biokerosene, LCH<sub>4</sub>, LH<sub>2</sub>). The cruise Mach number (3 to 8), supersonic dynamic pressure (20 to 100 kPa), Küchemann parameter are design variables that could be frozen or optimized for each mission. This improved version corrects some weaknesses of the previous version thanks to new models of aerodynamics, propulsion, masses, ascent and descent phases, and it introduces the supersonic dynamic pressure as an additional parameter to optimize. After presenting the sizing tool and the physical and implemented cost models, this paper provides the results and especially discusses the optimized designs obtained for different missions.

**Keywords:** *high speed, sizing, aircraft, cost*

### **Nomenclature**

$a$ - Acceleration	$MTOM$ – Maximum Take-Off Mass
$D$ – Drag	$PAX$ – Number of passengers
$g$ – Gravity acceleration	$S$ – Surface
$\gamma$ – Flight path angle	$T$ – Thrust
$Isp$ – Specific impulse	$\tau$ – Küchemann parameter
$L$ - Lift	$V$ – Volume or Velocity
$LF$ – Load factor	$z$ - Altitude
$M$ – Mach number or Mass	

### **1. Simulation tool**

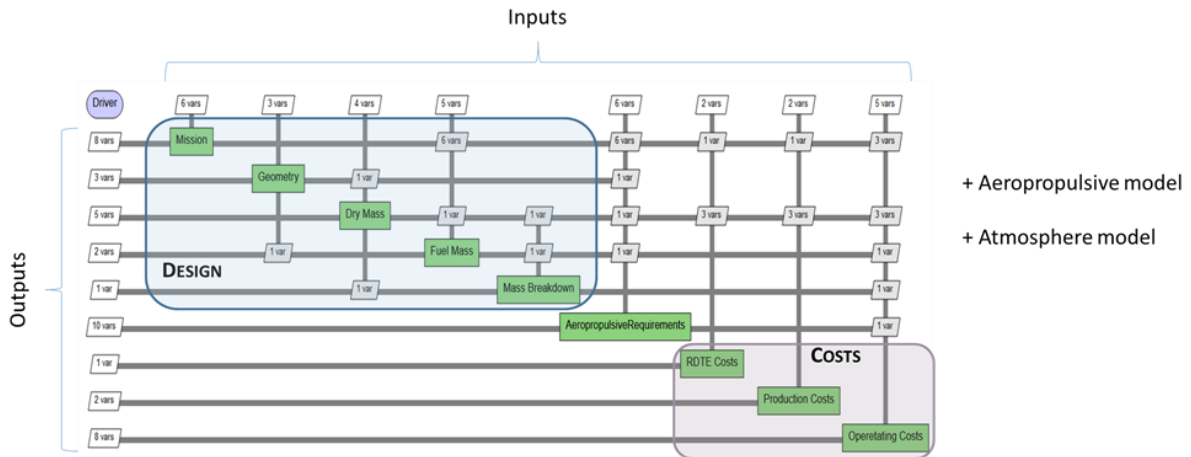
The sizing tool is based on the analysis & optimization framework OpenMDAO developed by NASA and the associated GUI WhatsOpt [1] [2] developed by ONERA. WhatsOpt allows the user to integrate easily all the disciplines which take part in the coupled numerical model as well as their inputs, outputs and the coupled variables from one discipline to another. Then, WhatsOpt is also able to generate automatically some code in Python language to adapt the interface of the disciplinary modules to OpenMDAO framework. WhatsOpt is also embedding many functionalities for the monitoring of the multidisciplinary process: DOE (Design of Experiment), optimization, post-processing of results. Finally, as it is coupled with OpenMDAO and Python scientific libraries, many solvers are available.

The dedicated WhatsOpt model is composed of a first sub-model which sizes the aircraft accordingly to the mission and geometric inputs, a second sub-model which provides the lift and thrust requirements

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during the mission for the sized aircraft, and finally a third sub-model which provides Research & Development, Production, Operational costs associated to the mission and the sized aircraft.



**Fig 1.** Multidisciplinary process with WhatsOpt web application

This tool could be used in a pure multidisciplinary analysis mode where range, number of passengers, type of fuel, Küchemann parameter, dynamic pressure (supersonic ascent, cruise, descent) are specified. It could also be used in a multidisciplinary optimization mode where Küchemann parameter, cruise Mach number, supersonic dynamic pressure could be parameters to be optimized so as to minimize maximum take-off mass (MTOM). In this case, a truncated Newton method (TNC) solver is used as a first step to reduce quickly the solutions space and then a Nelder-Mead solver is used as a second step to finalize the optimization process.

## 2. Simulation models

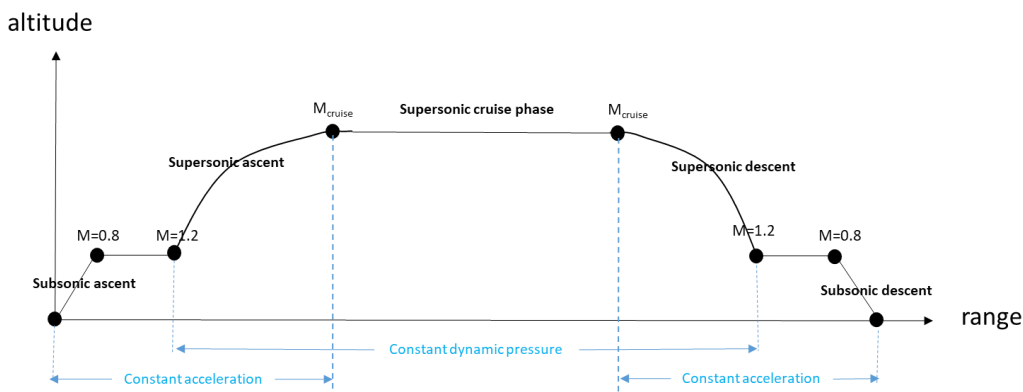
### 2.1. Physical models

#### Atmosphere:

The atmosphere model is ISA US 76 model.

#### Mission:

The mission is composed of the following phases:



**Fig 2.** Mission model

#### Aerothermodynamics:

The lift to drag ratio is set constant during the mission (except during transonic phase) and assessed thanks to the following formula [3]:

$$\frac{L}{D} = \frac{6(M_{cruise}+2)}{M_{cruise}} \left[ \frac{1.0128 - 0.2797 \ln\left(\frac{\tau}{0.03}\right)}{1 - \frac{M_{cruise}^2}{673}} \right] \text{ with } \tau = \frac{V_{tot}}{S_{plan}^{1.5}} \text{ the Küchemann parameter}$$

### Propulsion:

The assessment of specific impulse as a function of Mach number and type of fuel is based on quadratic functions featuring classical generic values:

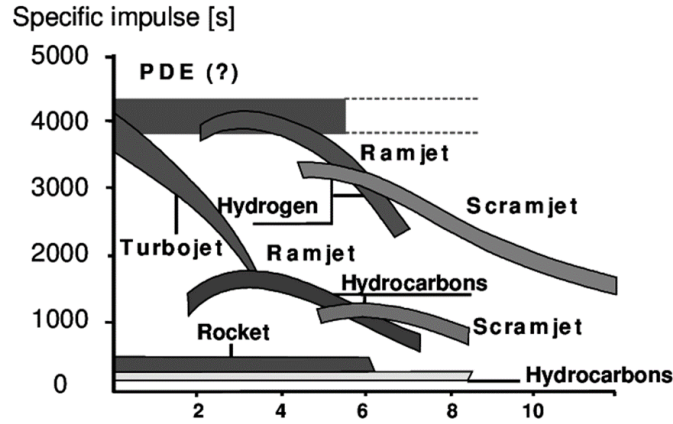


Fig 3.  $I_{sp} = f(M)$  for different engines and fuels

### Volumes & Surfaces:

Payload volume:  $V_{payload}(m^3) = \frac{M_{payload}}{\rho_{payload}}$  with  $\rho_{payload} = 100 \text{ kg}\cdot\text{m}^{-3}$

Fuel volume:  $V_{fuel}(m^3) = \frac{M_{fuel}}{\rho_{fuel}}$

Total volume:  $V_{total}(m^3) = \frac{V_{payload} + V_{fuel}}{\eta_v}$  with  $\eta_v = 0.7$

Plan surface:  $S_{plan}(m^2) = \left(\frac{V_{total}}{\tau}\right)^{2/3}$  with  $\tau = \frac{V_{tot}}{S_{plan}^{1.5}}$  the Kùchemann parameter

Wet surface:  $S_{wet}(m^2) = K_w \times S_{plan}$  with  $K_w = f(\tau)$  with  $f$  a polynomial function depending on the geometric topology of the vehicle as proposed in the following figure

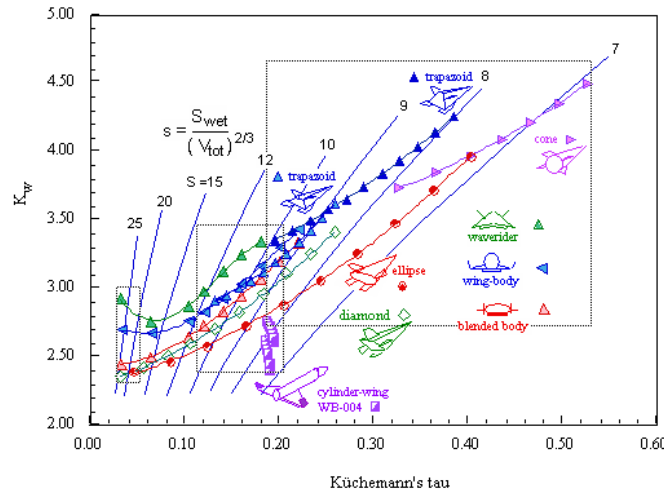


Fig 4.  $K_w = f(\tau)$  for different vehicle configurations

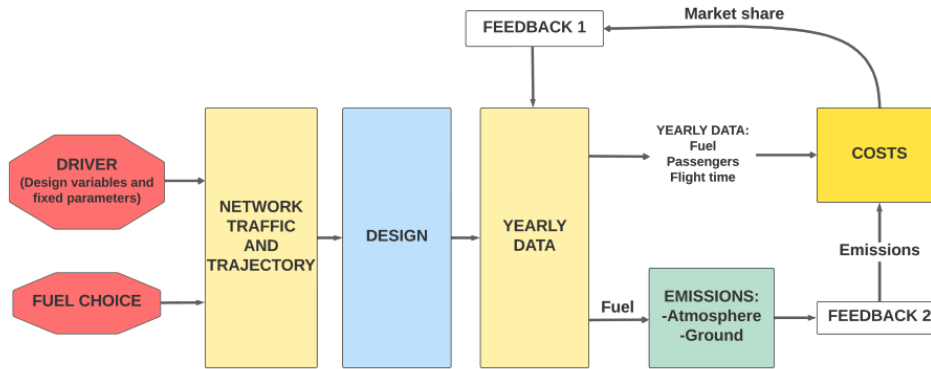
### Dry mass:

Payload mass:  $M_{payload}(kg) = 200 \times PAX$  with  $PAX$  the number of passengers

Systems mass:  $M_{systems}(kg) = r_{sys} \times MTOM$  with  $r_{sys} = \frac{M_{systems}}{MTOM} = 0.07$

Engine mass:  $M_{engine}(kg) = \frac{MTOM \times T_{sea\ level}}{ETW}$  with  $ETW = \frac{T_{sea\ level}}{M_{engine}} = 8.3$  (turbo-ramjet)





**Fig 6.** Architecture of future concept of operations MDAO model

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