# THE DEVELOPMENT OF A JET-UAV CONCEPTUAL DESIGN CODE

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## Abstract:

*Using the preliminary design of a medium range JET-UAV as the research background, a computer aided parameter optimization program which is suitable to the medium range JET-UAV is developed in this thesis. The main work of this thesis is the development of the analysis modules, such as the aerodynamics analysis and weight analysis modules which are applicable to the computer aided parameter optimization program of the medium range JET-UAV.*

*To check the validity of the computer aided parameter optimization program of the thesis, first of all, a JET-UAV manufactured by Italy (Mirach-100) was analyzed as a computation example, and the optimization parameter sensitivity analysis was done. Then two of the medium range JET-UAV design schemes were compared. The results showed that the computer aided parameter optimization program constructed in this thesis is feasible and reasonable. For the medium range JET-UAV preliminary design, the computer program is useful and helpful.*

## 1.Introduction

The system of the computer aided parameter optimization has three functions: First, the system can analyze the mission profile performance of the previous design. Second, it can optimize the parameters of conceptual design. Third it can analyze the optimization parameter sensitivity of the conceptual design.

The course of the optimization parameters of the conceptual design is as follows. First, the parameters of the conceptual design variable that need to be optimized and the regular parameters are put into the geometric module. Then the geometric module outputs mediates variable that meets the need of aerodynamics module and weight module. According to the conceptual design and the geometric data of aircraft, aerodynamics module estimates the drag and lift under the different speeds and altitudes. The weight module estimates the weight (the structure group , propulsion group, instruments group and so on), demand of utility and the parameters of the conceptual design. The weight of fuel is computed by using the mission profile performance module according to the max-course. After repeated calculating, we get the aircraft design weight. The propulsion module can show the ratio of the fuel consumption and the thrust of engine in the different flying speed and altitude according to the given characteristics of the engine, (the condition of utility and the position of the engine in the aircraft). According to the results of the above modules the mission profile performance module can estimate parameters of mission profile performance, such as maximum level speed, ceiling and maximum rate of climb. The parameters of mission profile performance are put into the object function to check whether it meets the need of the design or not. If it does not reach and achieve the goal of the design, it will be re-input according to the optimization until it satisfies the requirements of the design.

## 2.The mathematical model for the optimization of configuration parameters

### 2.1 Optimization method and penalty function

We use the Monte Carlo Method to make a rough selection of configuration parameters, then use the best date as the starting point to make further search with Random Ray Method, till the extrame of the penalty function is reached.

Both the Monte Carlo Method and Random Ray Method are used in the optimization of unconstrained problems. For the optimization of constrained problems, we usually turn the form of constrained problem into the unconstrained problem by penalty function.

## 2.2 The optimal object and the variables for optimization

A minimum launch weight of UAV is used as the optimal object. The constraints are maximum level speed $Ma_{max}$, the maximum load factor $ny_{max}$,, the specific excess power SEP and the maximum range $R_{max}$. The variables for optimization are wing area S, wing aspect ratio AR, wing tap ratio TR, wing sweep angle Xo and wing thickness ratio TC.

$$\text{Min } F=Wo(S,AR,Xo,TR,TC)+\Sigma Di \quad (i=1,4) \tag{1}$$

S.T. $Ma_{max} \geq 0.9$, $ny_{max} \geq 2.5$,
$SEP \geq 20m/s$, $R_{max} \geq 600km$.
And $1.8m^2 \leq S \leq 4.0\ m^2$, $4.0 \leq AR \leq 6.0$,
$0° \leq Xo \leq 40°$, $0.1 \leq TR \leq 0.5$,
$0.03 \leq TC \leq 0.1$

In formula (1), F is the object function; Di are the penalty factors for performances; If some performances satisfy the design requirements, the Di = 0, otherwise,

$$Di=(\text{calculated performance - design requirements})^2{}_i \times Wi \tag{2}$$

In formula (2), Wi are weighting factors, which are used to balance the importance of every performance constraints.

## 3.The analysis model of UAV configuration

The system of the computer aided parameter optimization is consisted of geometric module, weight module, aerodynamics module, propulsion module, mission profile performance module and optimization package. The above five analysis modules are peculiar to the design of an aircraft, while the optimization package can be used for any optimization.

## 3.1 Geometric model

From the main design variables, the geometric model outputs the intermediate variables for other analysis models. There are wing geometric model, fuselage geometric model, horizontal tail geometric model, vertical tail geometric model and so on. For example, from the wing 5 design variables (S,AR,Xo,TR,TC), calculated are wing span B, wing root chord Cr, wing tip chord Ct, wing aerodynamic chord Ca, wing 1/4 chord sweep angle $X_{1/4}$ , wing 1/2 chord sweep angle $X_{1/2}$ and so on.

## 3.2 Weight model

The total weight of UAV is composed of the structure group; engine system; instruments; fuel; recovery system and boosted rocket.

From the main configuration parameters and layout of UAV, the structure weight and other sub-system weights can be calculated. On the balance of all weights, the take off weight can be determined.

As an example, the wing weight formula is presented :

$$W_w = k \times [\frac{B \times S}{\cos X_{1/4}} \times \frac{1+2TR}{3+3TR} \times (\frac{W_D n_{y\max}}{S})^{0.301} (\frac{V_{\max}}{TC})^{0.497}]^{0.873} \tag{3}$$

In formula (3), $W_w$ is the wing structure weight of UAV; $k$ is the structural correct factor; $B$ is the wing span; $S$ is the wing area; $X_{1/4}$ is the wing 1/4 chord sweep angle; $TR$ is the wing taper ratio; $W_D$ is the design weight of UAV; $n_{y\max}$ is the design load factor; $V_{\max}$ is the maximum level speed; $TC$ is the wing thickness ratio. The weights of body, tail, engine system and other sub-systems can be calculated with the similar formula.

## 3.3 Aerodynamic model

The aerodynamic model estimates the rag and lift under different speeds and altitudes with the geometric parameters[].The design variables affect the aerodynamic characteristics of UAV. For example, the subsonic parasite drag of wing can be calculated as follow.

$$C_{D0W} = C_f [1 + L \times TC + 100 \times TC^4] R_{LS} (S_{WET} / S) \tag{4}$$

In the formula(4), $C_{D0W}$ is the subsonic parasite drag of wing; $C_f$ is the flat-plate skin-friction drag coefficient; $L$ is correct factor; $TC$ is the wing thickness ratio; $R_{LS}$ is the correct factor for the influence of mach number and wing sweep angle; $S_{WET}$ is the wetted area of wing; $S$ is the reference area. The drag and lift of other components can be estimated with DATCOM[8].

### 3.4 Flight performance model

For given configuration of UAV, based upon the outputs of aerodynamic model, weight model, propulsion model and so on, calculated are the point performances (maximum level speed, ceiling, climb rate, SEP, sustained turn load) and mission profile performances (maximum range, maximum endurance, climb time and so on).

## 4. The examples and the analysis

### 4.1 Prove the code by exist UAV

To check the validity of the design code in this paper, a jet UAV made by Italy (Mirach-100) was analyzed as a computational example. The error of the computed performance of flight is within one percent compared with Mirach-100 (Table 1).The results show that the design code in this paper is feasible and reasonable.

**Tab.1 comparison of calculated results with the practical data from Mirach-100**

| | $V_{max}/m\cdot s^{-1}$ | Ceiling/m | $Vy_{max}/ m\cdot s^{-1}$ | take off weight/kg | fuel weight/kg |
|---|---|---|---|---|---|
| Mirach-100 | 238.0 | 9000 | 33.0 | 260.0 | 55.0 |
| The paper | 237.1 | 8919 | 33.3 | 263.3 | 54.2 |

### 4.2 The analysis of preliminary configuration

The preliminary configuration is a high subsonic UAV. The propulsion is jet or turbofan. The 3d diagram and analyzed take off weight, fuel weight, maximum speed, ceiling and endurance are showed in Fig.1

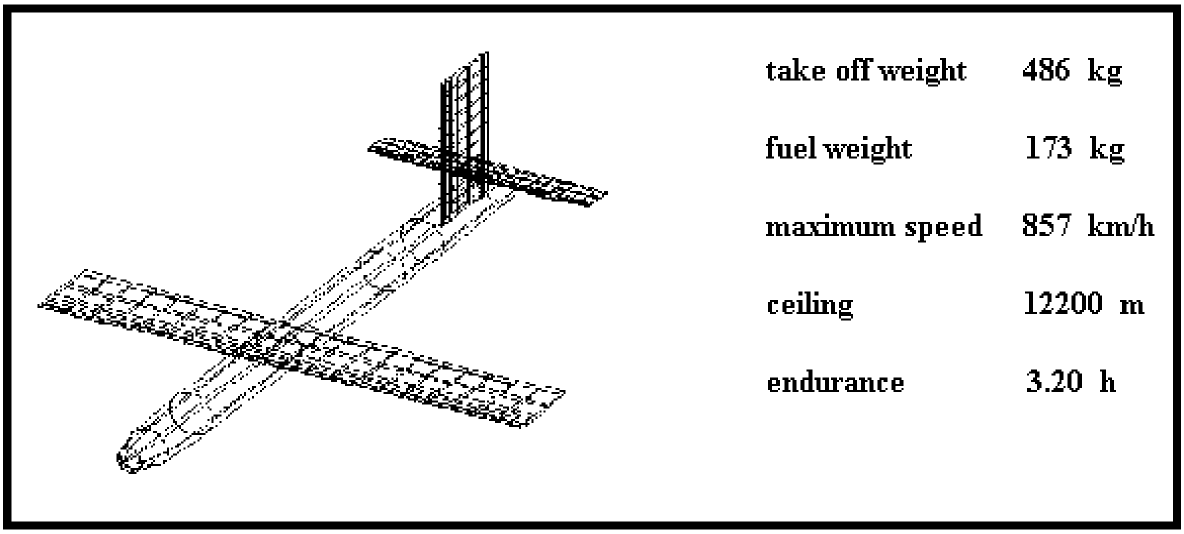
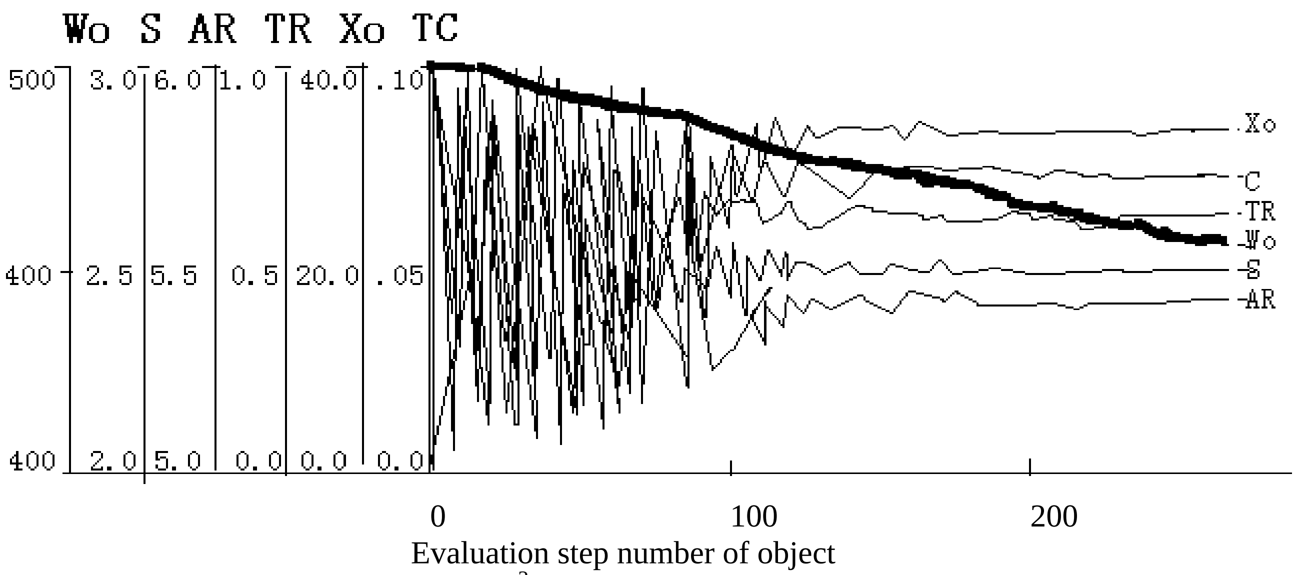



**Fig.1 Preliminary configuration**

### 4.3 The optimization of configuration parameters

With Monte Carlo Method and Random Ray Method, the optimization of object function(1) is performed. The evaluation of object function and variables is showed in Fig.2. Take off weight and variables to be optimized are showed in Tab.2.After optimization the take off weight decreases from 486kg to 457kg. The optimized configuration of UAV is showed in Fig.3.




Wo-Take off weight/kg; S-Wing area/m$^2$; AR-Wing aspect ratio; TR-Wing taper ratio; Xo-Wing sweep angle/°; TC-Wing thickness ratio

**Fig.2 Evaluation of object and variables in the optimization of take off weight**

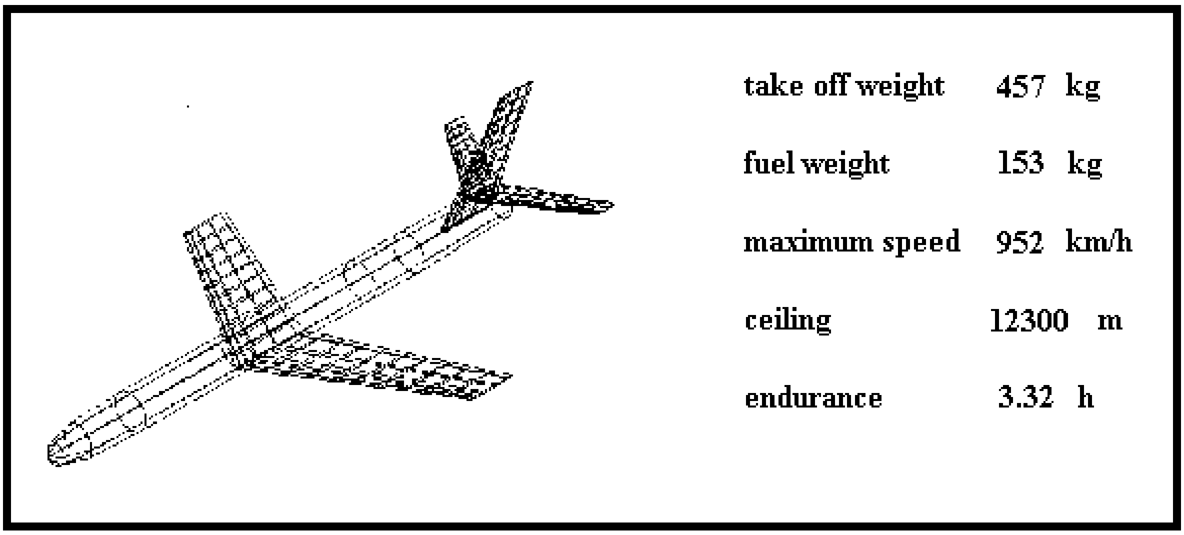



**Fig.3 configuration after optimization**

## 5.Conlusion

**(1)**The computer aided the parameter optimization program constructed in this paper is feasible and reasonable.

**(2)**The optimization package(Monte Carlo Method + Random Ray Method) is effective and reliable.

**(3)**The JET-UAV CONCEPTUAL DESIGN CODE established in this paper can be used in the practical engineering.

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