Project of an UAS – a manual (description) for preparation of the projects – prepared by Z.Goraj (March 2020)

Dates projects should be completed: (1) 26.03; (2) 9.04; (3) 30.04; (4) 14.05; (5) 28.05; (6) 4.06

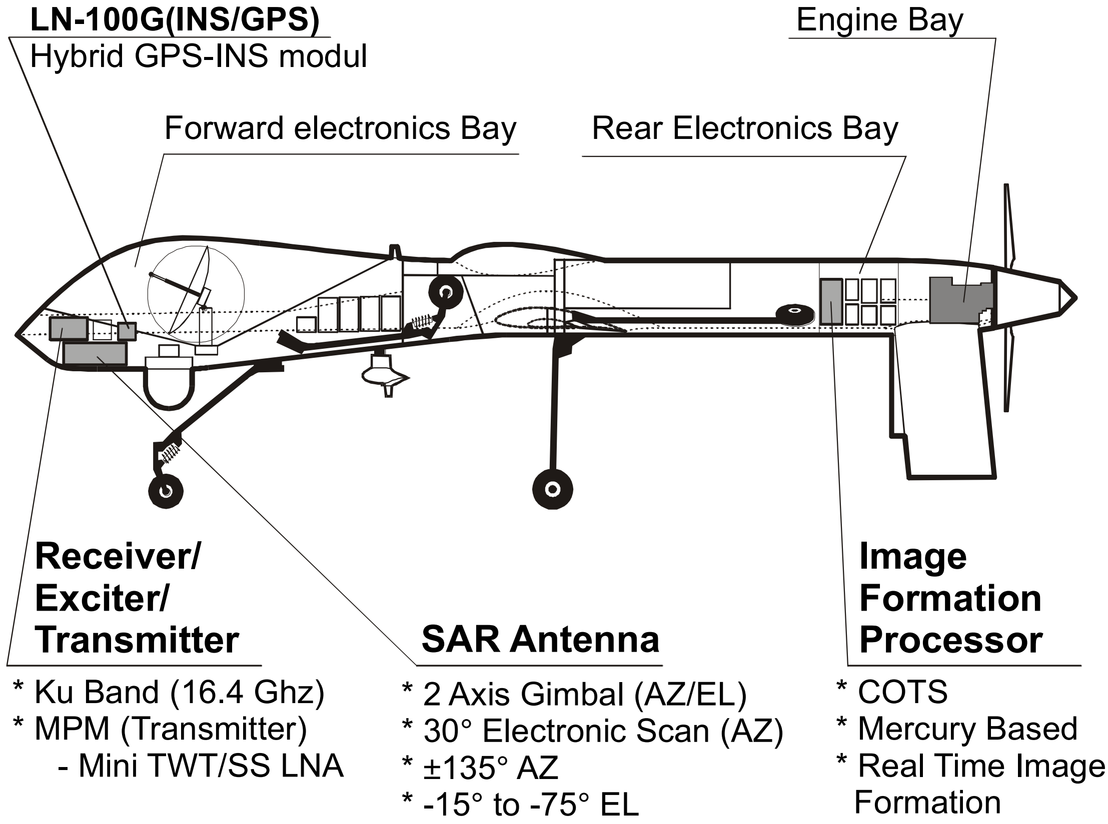
(0) Organizational remarks for team project within the subject „Unmanned Aerial Systems ”

1. Number of design group is equal to the number of the team and number of the mission defined in the document entitled: Unmanned Aerial Systems – projects for choice;
2. Design group consists of 3 or 4 students formed on the basis „good links and mutual relations”;
3. Each group has to develop a short document with project schedule and individual responsibility. In this document it should be written how the group is managed, who is a group leader and what are responsibility of each group members. How do you act if any team member will not fulfil his/her responsibility and how the recovery is planned? All team member must reveal their contact „coordinates”, i.e. e_mails, phones etc. All these data must be included in project no 1 and they have influence on the mark the group get for project no 1;
4. All official documents students are using in design process (including successive projects positively assessed by supervisor) should be kept in a carton folder (please avoid the plastic folder because it create some difficulties for project supervisor when writing some remarks on the plastic cover page). On the carton folder first page the filled-in template (appendix_no_2) should be attached (glued). All individual (successive) projects must start with cover page of the individual project (see page 2 of appendix_no_2). When arriving for project consulting the design team must have all former projects in the carton folder;
5. Final mark of the project is equal to the mean value of all 6 projects marks. Necessary condition to pass is to get positive marks for all 6 projects. When project is delayed on one week with respect to the schedule the respective mark could be decreased on point 1, after 2 weeks the mark is decreased on 2 points and after 3 weeks on 3 points respectively. When delayed on more than 3 weeks the project could not be positively assessed.

(1) Selection of sensors, antennas, navigation systems, data links, frequencies and other avionic systems

Select sensors, antennas, navigation systems, data links, frequencies and other avionic systems the best suited to the mission and aircraft size. Select and describe the main aircraft parameters: weight, dimensions, sensor’s resolution, range of signal and range of aircraft, power required to operate the on-board equipment.

Suggested sources: Jane’s Unmanned Aerial Vehicles and Targets (MEiL library), Internet, books. Include a copy of original source if taken from internet (website address is not sufficient, because it can disappear within days or weeks).
Look at the example bellow:

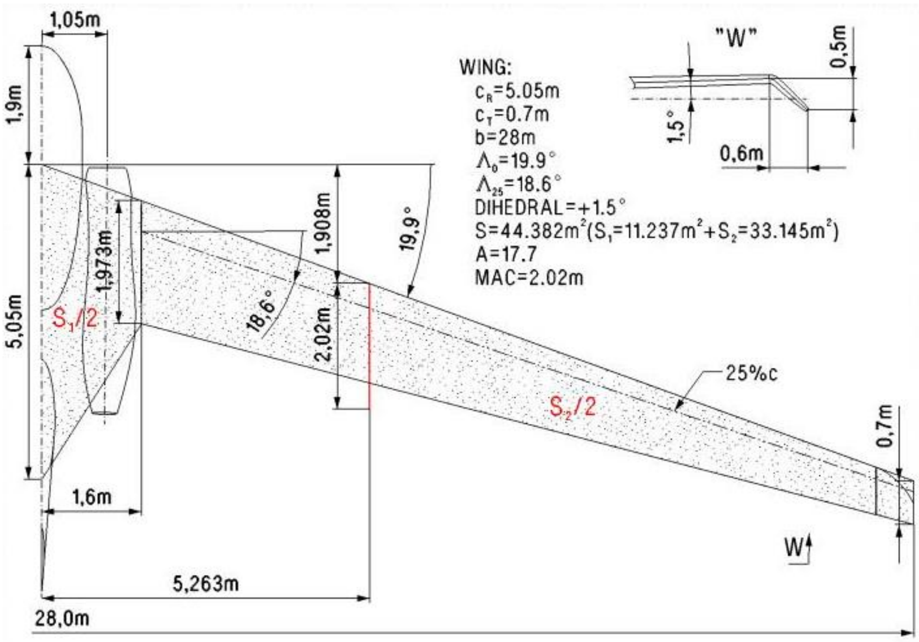


Contemporary MALE UAV – a typical SAR mission presented

(2) Selection of main geometrical and weight parameters of the aircraft

Prepare a handmade sketch of the aircraft: a perspective view and 3 perpendicular projections
Propose the most important (fundamental) parameters:

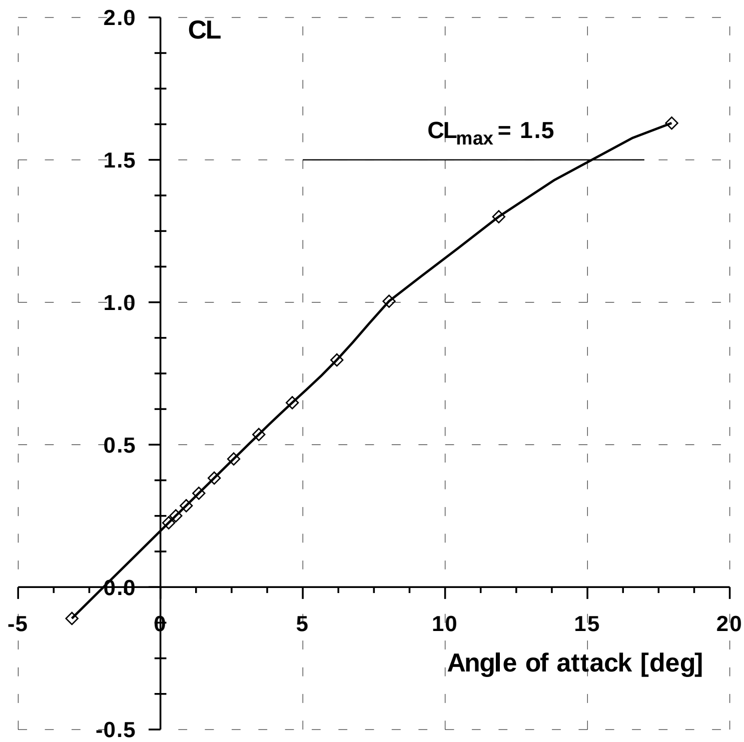
Gross wing area	S [m^2]
Wet area	S_W [m^2]
Wingspan of the aircraft	b [m]
Wing aspect ratio	A=S/b2 [-]
Mean Aerodynamic Chord	MAC [m]
Wing taper ratio	$\lambda=C_T/C_R$ [-]
Wing thickness ratio	g=t/c [-]
Body length	L [m]
Engine selection	type, power (thrust), producer, symbol, etc
Wing loading	W/S [kg/m^2]
Thrust loading (power loading)	W/T [kg/N] (W/P [kg/hp])



Przykład wymiarowania geometrii płata i kadluba

(3) Computing the main aerodynamic characteristics

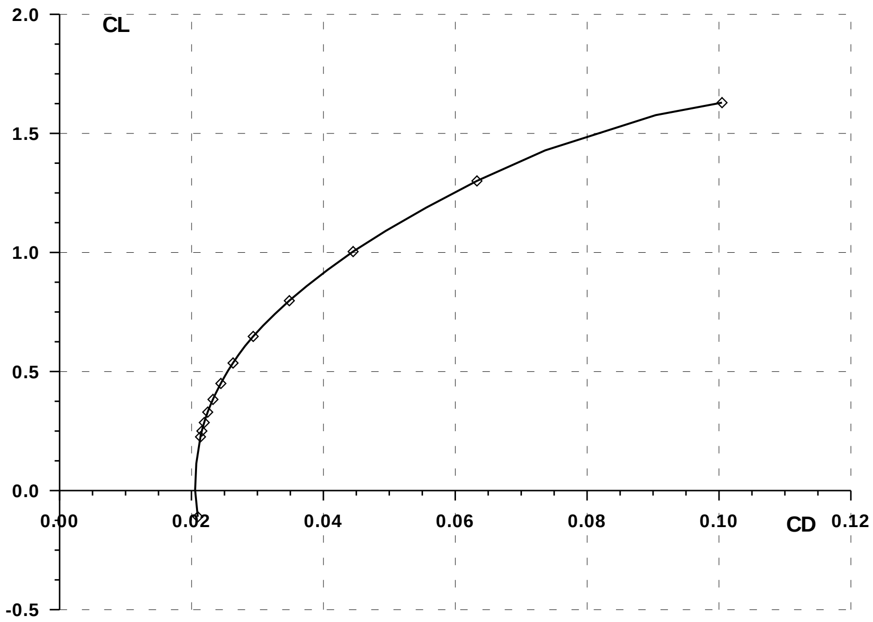
CL=f(α)



Clmax clean

Clmax with flaps for takeoff and landing

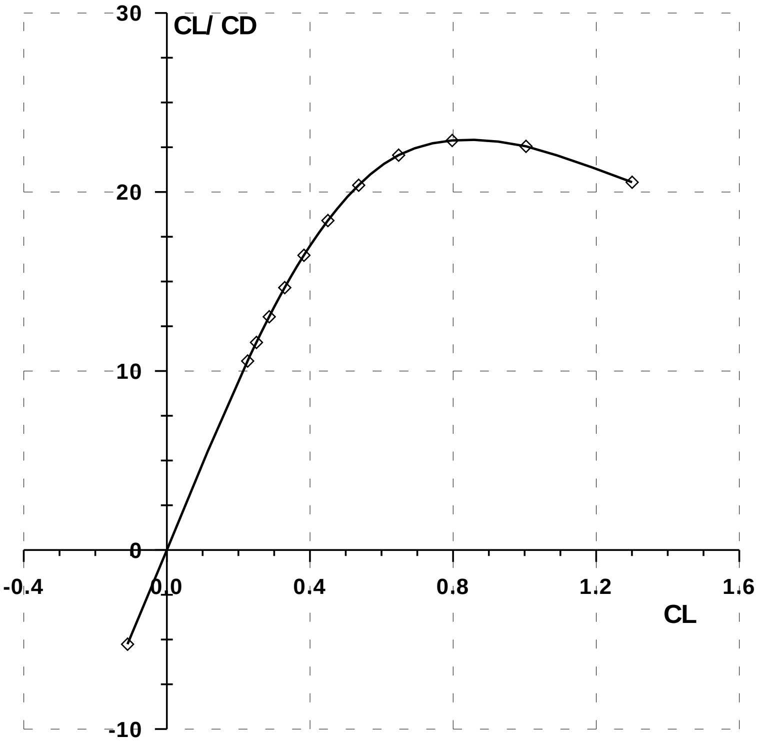
CD=f(CL)



CD_0 breakdown

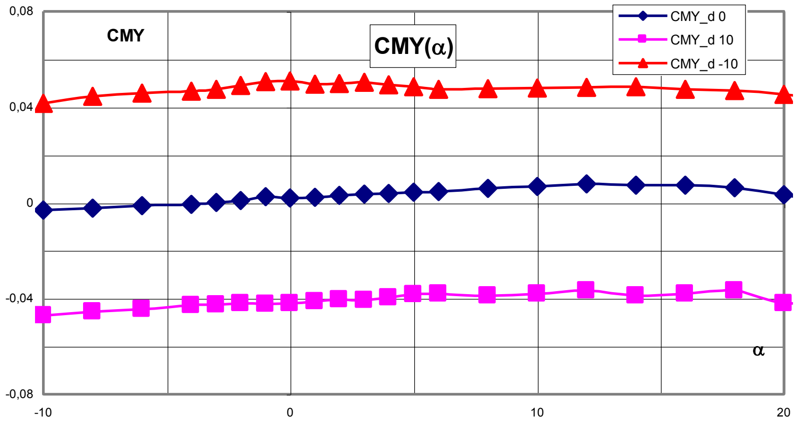
Parasite drag	C_D	S_i (reference area)	$C_{Di} * S_i /S$
Wing	0,0065	10,22	0,0065
Fuselage	0,08	1.35	0,010568
2 beams	0,06	0.2	0,001174
Empenage	0,006	2,1	0,001233
Total parasite drag	0,01948	10,22	0,01948

CL/CD=f(CL)

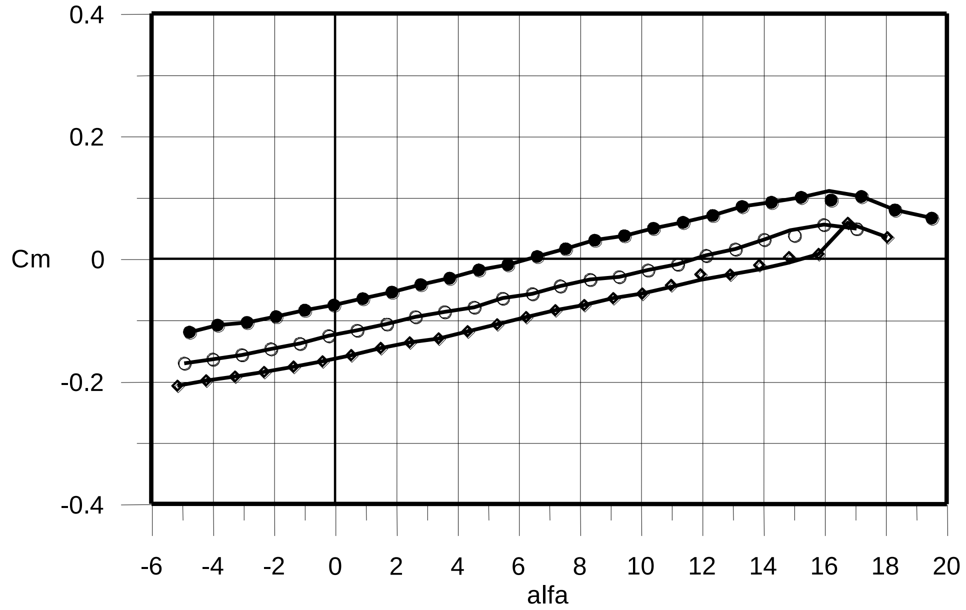


Pitching moment coefficient, the best if divided into 2 parts: wing + fuselage (body) and empennage (C_{w+B} and (separately) empennage (tailplane) C_{mh} in the form of 2 coefficients: C_{mh0} (alfa=delta_h=0) and

$a_1 = \frac{\partial C_{ZH}}{\partial \alpha}$ *and* $a_2 = \frac{\partial C_{ZH}}{\partial \delta_H}$ (under the assumption that a1 and a2 are constant, independently on α, δ_H, Ma).



Pitching moment coefficient (tailplane is not included) computed about a quarter point of MAC versus angle of attack for clean configuration (d=0), flap-tabs deflected down (d=10) and flap-tabs deflected up (d=-10); Ma=0.5, Re=28 mln



MODEL SAMOLOTU FAMILY-JET

Run	β	δ_F	δ_e	δ_r	δ_{al}	δ_{ar}	v[m/s]
772	0°	0°	0°	0°	0°	0°	40 bu
773	0°	20°	0°	0°	0°	0°	40 bu
774	0°	60°	0°	0°	0°	0°	40 bu

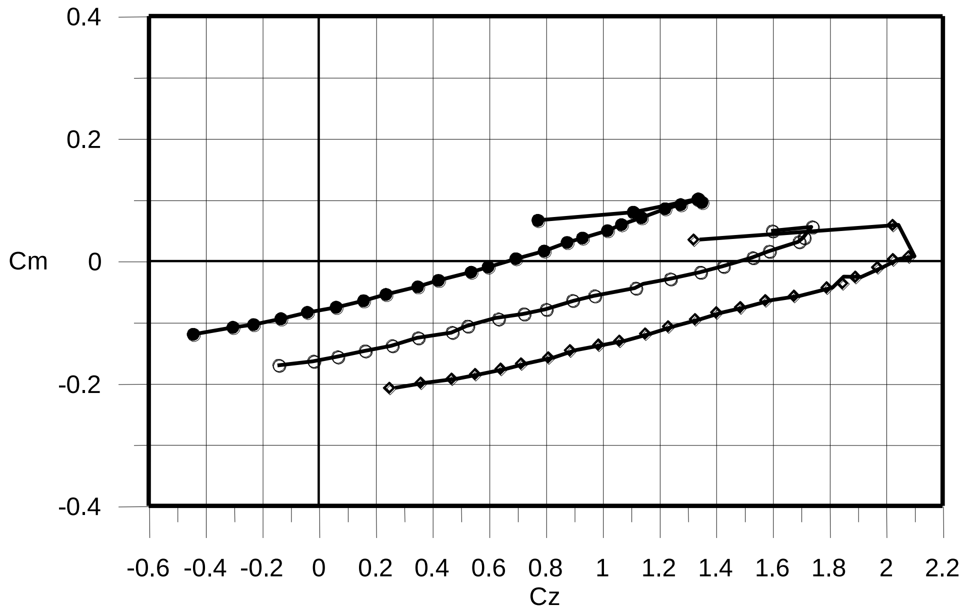
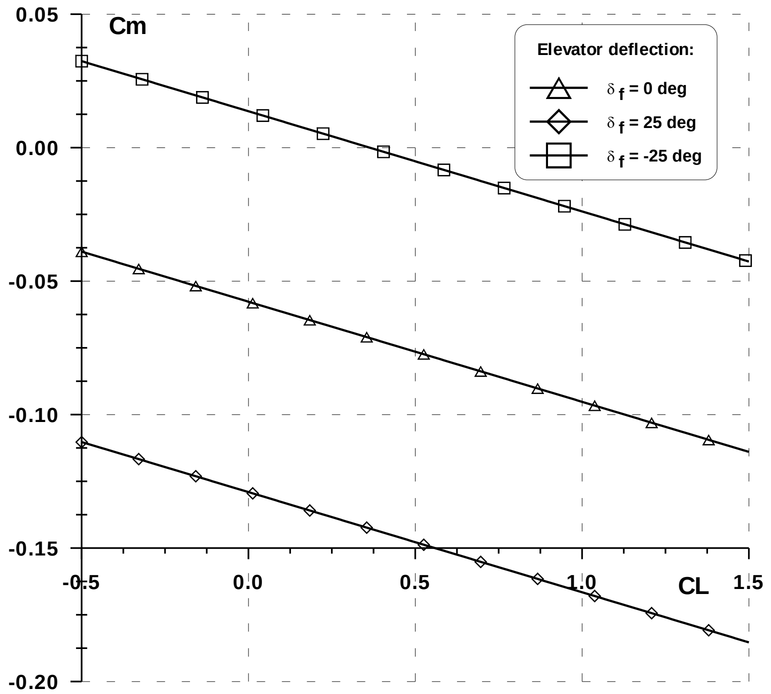


Figure above shows an example of pitching moment characteristic $C_{w+B} = f(\alpha)$ and $C_m = f(C_Z)$ (where C_Z means C_L) for different flaps deflections (wing + Body only; tailpalne is excluded)

In some cases it is suggested to present the entire (whole) pitching moments for 3 typical elevator deflections (or elevons if we deal with flying wing configuration without tailplane), for example (see figure bellow):

Cm=f(CL) for REFERENCE C.G. - for $\delta e=0$, $\delta e=-25^0$, $\delta e=25^0$



One can notice, that pitching moment of an aircraft could be written as

$$C_{mA} = C_{m,w+B,A} - \frac{l_H\, S_H}{c_a\, S}[\alpha\{(1-\frac{\partial\varepsilon}{\partial\alpha}) + \alpha_{zH}\}a_1 + \delta_H a_2],$$

where

$C_{m,w+B,A}$ - pitching moment of wing and body with respect to one quarter of Mean Aerodynamic Chord (¼ MAC);

a_1, a_2 – gradients of tailpalne lift with respect to angle of attack and elevator deflection, respectively,

$\frac{\partial\varepsilon}{\partial\alpha}$ - downwash derivative (gradient of angle of downwash with respect to angle of attack),

α_{zH} - angle of tailpalne setting with respect to Mean Aerodynamic Chord (MAC),

$\kappa_H = \frac{l_H\, S_H}{c_a\, S}$ - dimensionless volume of the tailplane.

(4) Project of internal loaded structure + weight analysis

1. Prepare the design concept of the main wing spar;
2. Propose a fuselage design of loaded structure
3. Propose how to joint the wing with fuselage
4. Perform the analysis of wing bending moment

$$\sigma = \frac{M_g}{W}; \ where \quad W = \frac{I_y}{z_{\max}}$$

whilst:

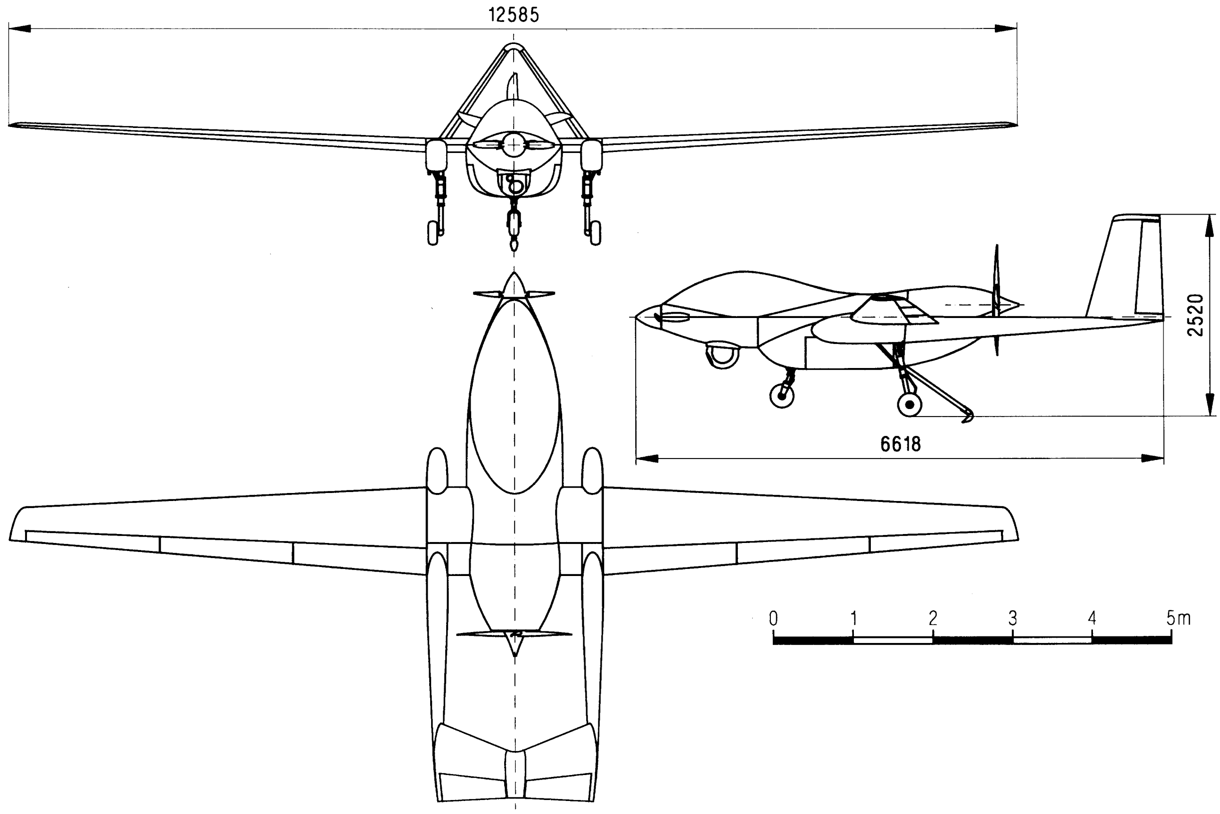
Mg – bending moment, changeable along wing span [N * m];

$W = \frac{I_x}{Z_{\max}}$ - index of the strength of wing (spar) cross-section [m^3]

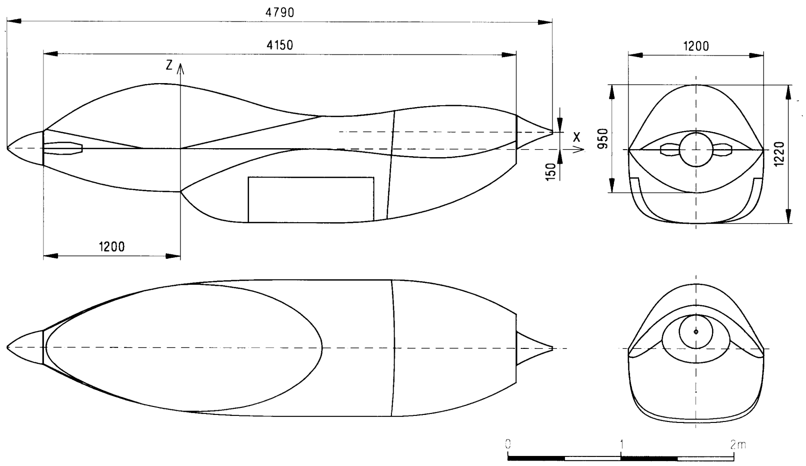
I_y - moment of inertia of spar cross-section [m^4];

Z_{max} – distance between spar flange and the spar neutral axis [m].

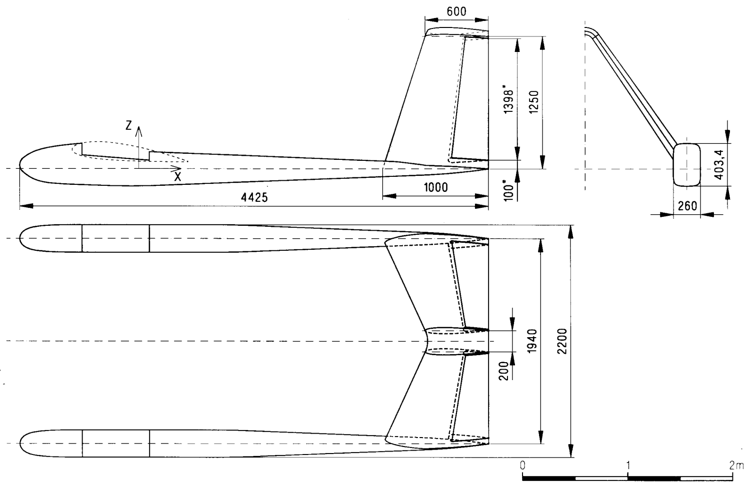
σ - maximum stress value in the spar flange [M Pa].



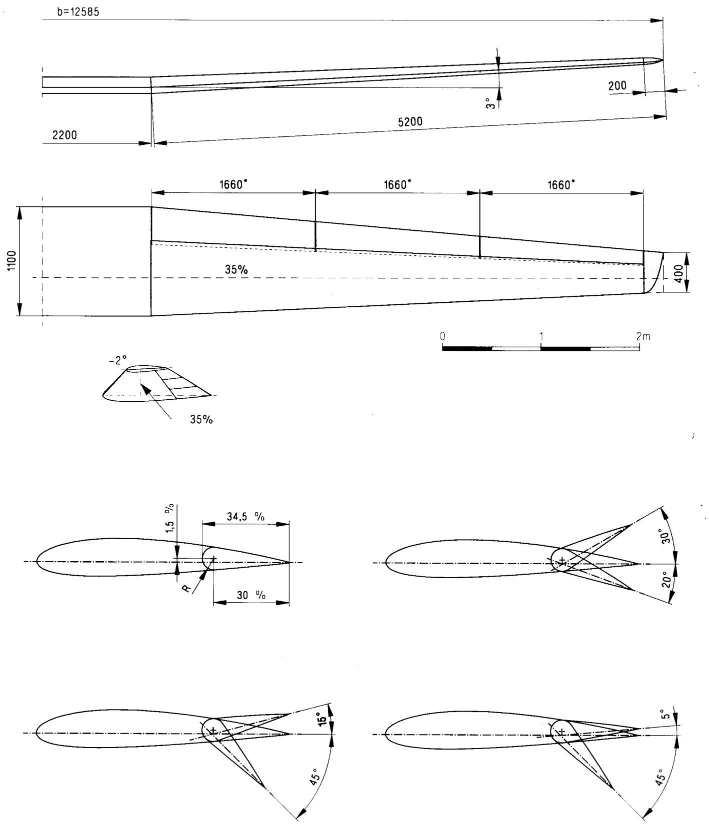
Fuselage dimensions



Wing planform dimensions
Horizontal tail planform dimensions
Vertical tail planform dimensions
Nacelle dimensions
Tail-boom dimensions (where applicable)

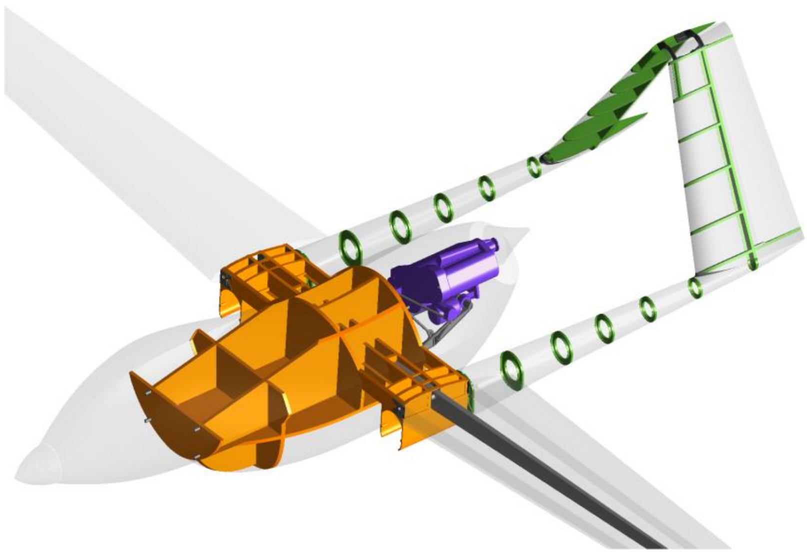


Wing airfoil definition NACA 2415
Tail airfoil definition NACA 0012
Flaps, ailerons, elevator and rudder definition (including angular travel)

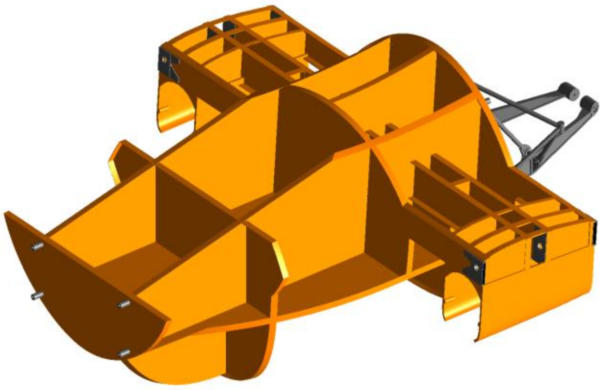


From left to right and from top to bottom: (1) non-deflected flap, flaperon and aileron; (2) aileron; (3) flaperon and (4) flap

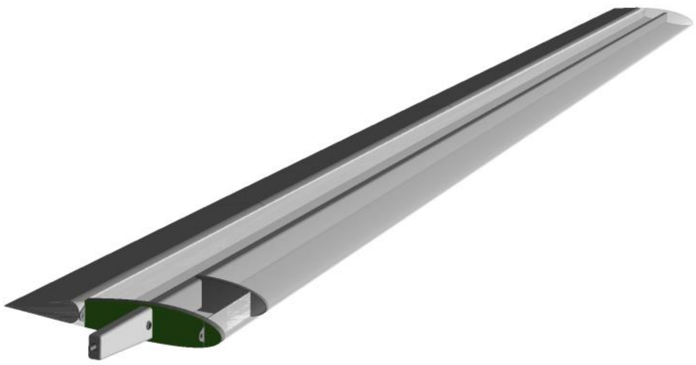
Main structural elements

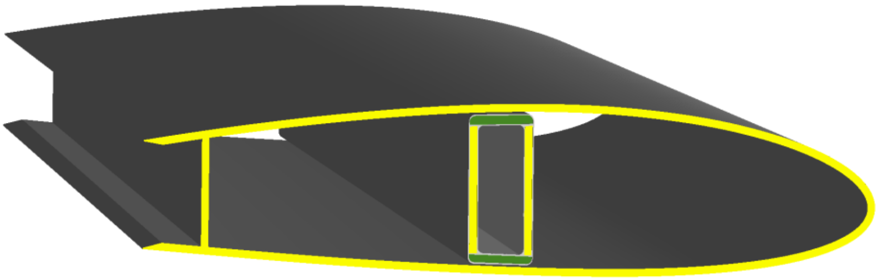


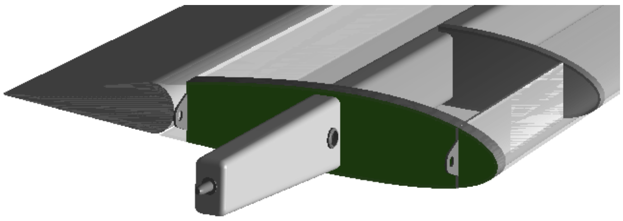
Fuselage main longerons and frames arrangement

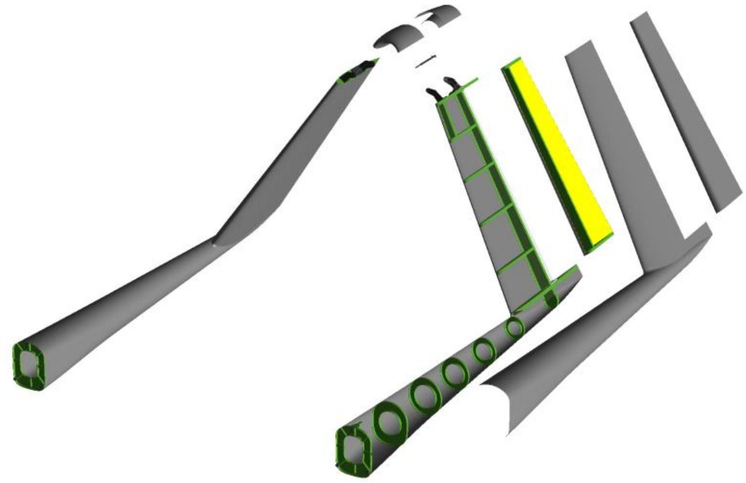


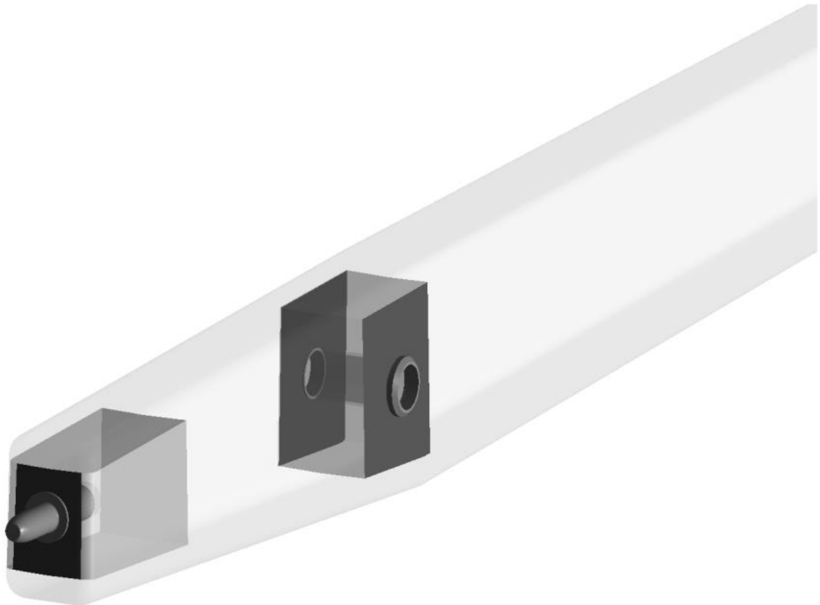
Wing main spars and ribs arrangement



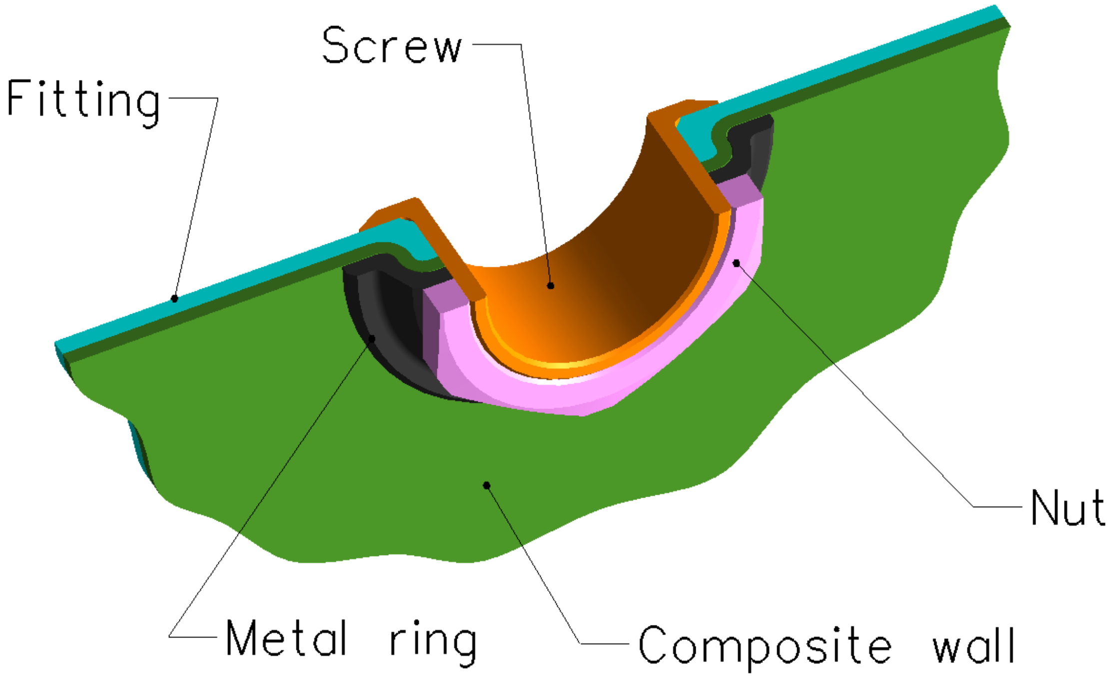






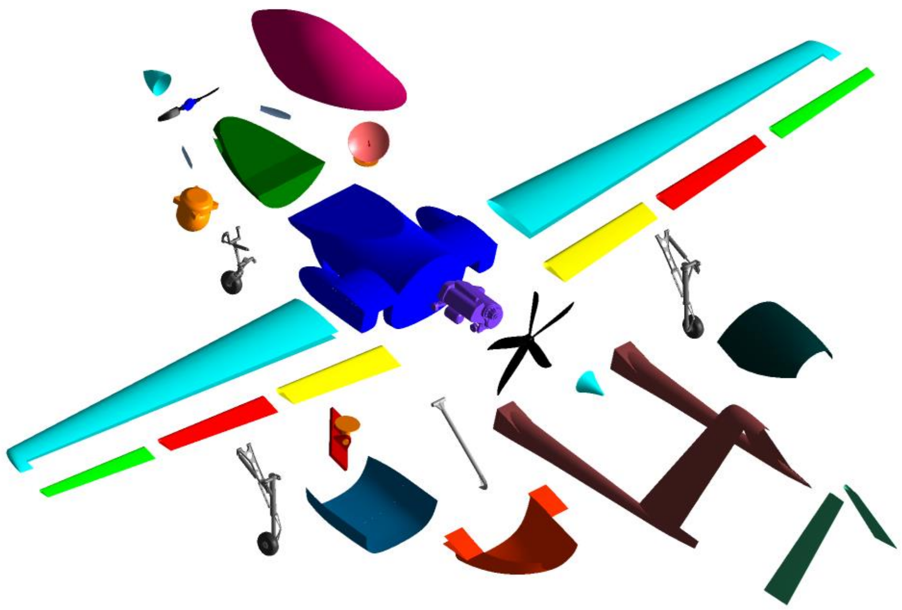


Box spar of the PW-103 wing – this scheme shows how the spar is attached to the fuselage structure



Joining of the composite spar wall with metallic fitting using the so-called „composite lock”

Dividing the structure into main elements (parts):



Mass distribution:
Structure
Propulsion
Systems

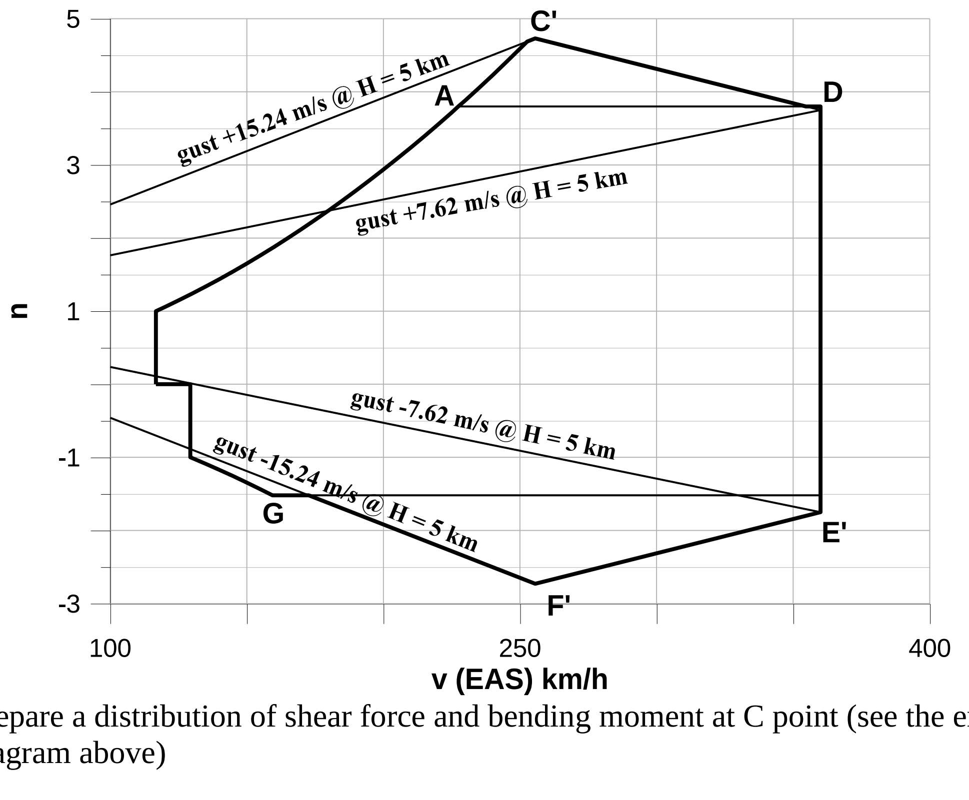
Avionics
Empty weight
Fuel
Payload
Takeoff weight

Max Take-off Weight (MTOW)
Empty weight
Fuel weight
Payload
Fuel weight coefficient = weight of fuel / MTOW
Coefficient of empty weight = empty weight / MTOW

Center of gravity location and travel (centrogramme)

C.G. With empty weight
C.G. With payload installed
C.G. travel with fuel
Definition of aft & forward C.G. limits

V-n diagram

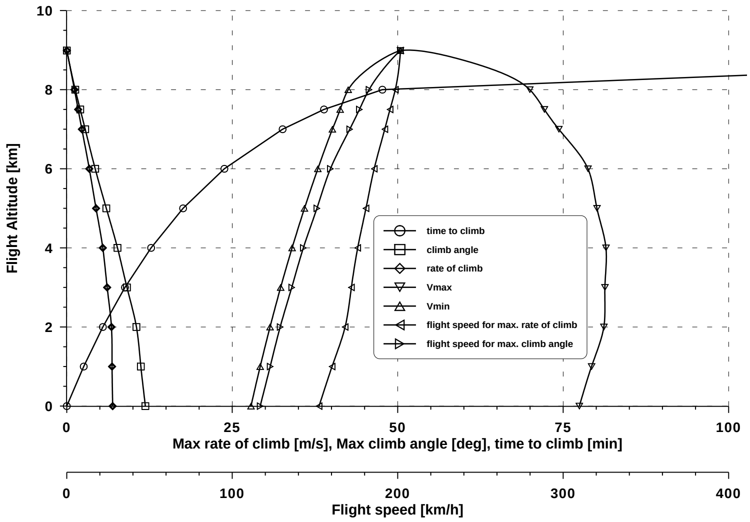


- Prepare a distribution of shear force and bending moment at C point (see the envelope diagram above)

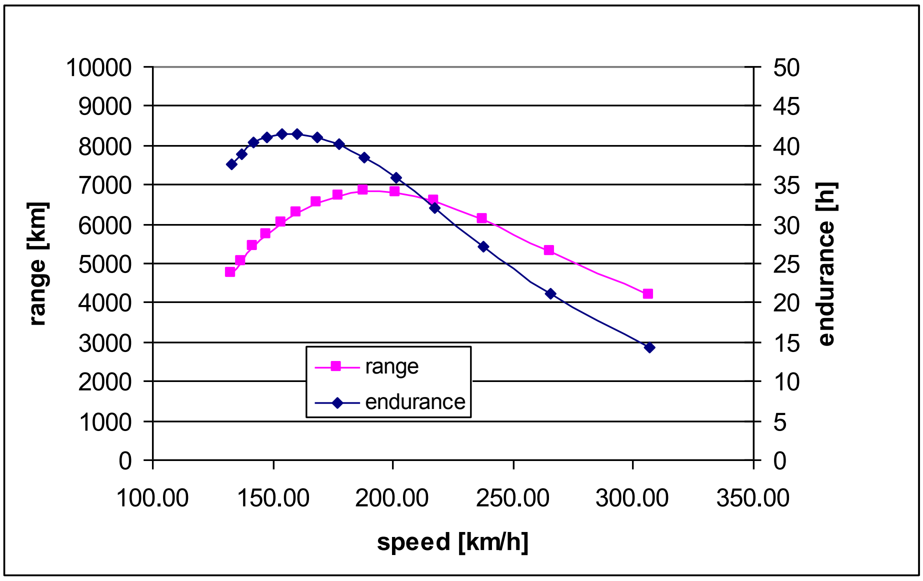
Remark: Project no 4 must include a distribution of stresses versus wingspan and comparison of maximum stresses with the level permissible stresses for selected material, for example for carbon fibre or glass fibre structure. A topology of spar and number of fabric layers together with its basic weight must be assumed.

(5) Assessment of aircraft performance

Vstall 107 km/h (at see level)
Vmax 325 km/h (h=4000 m)
Vc – cruise velocity in indicated airspeed
130 km/h (EAS for longest endurance)
152 km/h (EAS for longest range)
Max Vc 280 km/h
Rate of climb (SLS) 7 m/s
Max Ceiling altitude 9,00 km
Flight envelope (at takeoff weight)



Endurance versus range – for several payloads weight for typical mission



Take-off & landing
Takeoff distance (at takeoff weight = 930 kg $C_{L,max}$=2.0) 415 m (at 50 feet obstacle)
Landing distance (at takeoff weight = 710 kg $C_{L,max}$=2.0) 585 m (from 50 feet obstacle)
Landing distance (at takeoff weight = 930 kg $C_{L,max}$=2.0) 688 m (from 50 feet obstacle)

(6) **Cost analysis**

Perform cost analysis basing on one of the assumption from your country (monthly salary of engineer and technician plus cost of the labour; for example if employee is paid say 10 USD, how much extra the company must pay for his/her assurance, pension etc).

Basing on Raymer, Roskam, Jenkinson or other author is risky, because these books refer mainly to old, metallic design, for example:

1. D.Raymer: Aircraft Design: A Conceptual Approach, AIAA Educational Series.
2. L.R Jenkinson et al., Civil Jet Aircraft Design. Arnold, 1999.

Table 1: Assumptions taken for today and future UAV comparison (MALE class)

	Today technology	Future technology
Structure cost (M$)	4	2
Operating flight hours per year per UAV	2000	4000
Operating team (months*persons)	40	10
MTBUL (H)	10 000	50 000
MTBF (H)	10	20

*The distribution of TOC (in $ /(H*UAV) was presented by Sh.Tsach in UAVNET meeting in Rochester [21] and is given here in Tab.2.*

Table 2: Cost distribution (in $ /(H*UAV) for unmanned and manned airplane

	Today technology	Future technology
UAV acquisition	100	25
Insurance	100	10
Operating team	720	90
Maintenance	920	125
Overhead	720	90
Others	480	190
Total cost	3040 [$/H]	530 [$/H]

An example of cost analysis for mini class UAS (Israeli K70 system):

UAV	K-70	4 A/C / month	6 A/C / month
	Development & Preproduction Duration	2 years	2 years
	Project Duration (years)	8.3	6.2
	A/C Production Cost	32.7 K€	32.7 K€
	A/C Price	56.8 K€	55.7 K€
	Financial Data	Net Present Value	Net Present Value
	Development & PreProduction Cost	4,552 K€	4,559 K€
	Production Cost (300 A/C)	9,067 K€	9,249 K€
	Financing Cost	680 K€	500 K€
	Total Expense	14,299 K€	14,308 K€
	Years to Break Even(from project start)	6.8	5.2
	Number of A/C Produced @ Break Even	232	232
	Total Revenue	15,729 K€	15,739 K€
	Rates		
	Loan Interest Yearly Rate	5%	5%
	Investment Interest Yearly Rate	4%	4%
	Profit Percent	10%	10%

System	K-70	Number of Items	Single Item Price	Total Price
	A/C Price	2	57 K€	114 K€
	Payload Price	2	20 K€	40 K€
	Ground Control Station Price	1	13 K€	13 K€
	Ground Data Terminal Price	1	9 K€	85 K€
	System(s) Price			175 K€