APPENDIX 3-5

UAV SAFETY OBJECTIVES

1. CONTEXT

Safety objectives have been used as a means to define & justify the civil aircraft characteristics.

These safety objectives are oriented to on board people protection and are defined by the FAR/JAR 25/23 regulations.

As there is no people on board of UAV, safety objectives criteria for UAV must be redefined and oriented to on ground people protection.

2. ON GROUND VICTIM CRITERIA

A first step to define safety objectives is to select a figure corresponding to an "acceptable" probability for on ground victims per fatal UAV accident. This figure might be justified based on the today on ground victim due to the flying machines as light & transport aircraft, military aircraft or helicopters.

UAV must not be considered by civilian population as more risky that other flying machines. At the opposite the criteria must allow the development of UAV at an acceptable economic cost.

Most of the victim statistics published are relatives to on board people, and the few published statistics relatives to on ground victims are not reliable.

US Navy has published figures for "risk of aircraft flying overhead" and estimated the ground casualties at a rate of 1,8 victims per million flight hours (*).

It might be suggested to use for UAV the conservative criteria of :

One victim per million UAV flight hours.

Note : Air transport statistics for large aircraft provide figures of about 50 victims per million aircraft flight hour but they are passengers, they are aware of the risk.

(*) : Range safety criteria for unmanned air vehicles. Rationale and methodology supplement to doc 323-99

3. METHOD TO ESTIMATE CRASH ENERGY & LETHAL AREA

This method of calculation is not limited to UAV but must be applied to all flying machines. Application of this method to the aircraft crashes (civil & military) and correlation of the figures with the statistics will allow the validation of the method.

The method consists of an estimation of the energy of the flying machine and an estimation of the lethal crash area. For an explosion energy is a cubic function of the radius ($E = d^3$) and lethal area a square function of the radius ($Ac = d^2$).

$Ac = k.E^{2/3}$ Ac = lethal area E = energy

3.1. Aircraft energy , Kinetic energy

Estimation of crash energy depends of variable parameters. There are two main sources of energy, the kinetic energy and the fuel energy. To simplify the fuel energy will be considered proportional to the air vehicle kinetic energy. Aircraft energy will be considered as proportional to kinetic energy.

Kinetic energy is a function of the mass & of the speed :

$Ec = ½.M.V^2$ M = mass V = speed

Air vehicle mass vary from MTOW (Maximum Take Off Weight / Mass) to MW (Minimum Weight / Mass)

Air vehicle speed vary from VMO (Maximum 0perating speed) to Vs (Stall speed)

To unify and simplify the determination of the average kinetic energy it might be useful to determine the energy at a given "lift coefficient" Cl (which is roughly the same on flying machines) :

$M.g = ½.\ \rho_0.\ Cl.\ Sref.\ V^2$ Cl : lift coef Sref : reference Wing surface

$V^2 = k1.\ M / Sref$ At a given Cl

$Ec = ½.\ k1.\ M.\ M / Sref$

(0) **$E = k2.\ MTOW^2 / Sref$**

Energy is based on well identified characteristics published in the "aircraft data sheet" as MTOW and reference wing surface.

3.2 Lethal crash area

Lethal crash area can be determine as :

(1) **$Ac = k.\ (MTOW^2 / Sref)^{2/3}$**

Lethal crash area will have to be calibrated based on the experience of crashed aircraft. It might be suggested the following figures.

MTOW : 17 000 kg Sref : 42,5 m^2 Ac : 1 000 m^2

k is determined equal to 0,028

k = 0,028

(1a) $\boldsymbol{Ac = 0{,}028.\ (MTOW^2/Sref)^{2/3}}$ Ac & Sref in m^2 MTOW in kg

3.3. Applications

Application of the "Ac" formula (1a) to different sizes of flying machines is provided in the following table :

AIRCRAFT TYPE		Mass	Sref	Wing loading	Lethal Surface
		kg	m2	kg/m2	m2
Military	Combat aircraft	17000	42,5	400	**1000**
JAR 25	Boeing 747	350000	520	673	**10627**
	Falcon 2000	20600	49	420	**1175**
JAR 23	Commuters	6800	40	170	**307**
	M > 6000 lbs reciprocating	5700	38	150	**251**
	M < 6000lbs turbine	1800	15	120	**100**
	M < 6000lbs reciprocating	800	13	62	**37**
JAR VLA		750	15	50	**31**
		300	7,5	40	**15**
Ultra Light		100	2,5	40	**7**
		25	1,25	20	**2**

4. DETERMINATION OF ON GROUND VICTIMS

The determination of victim number is based on lethal crash area and on over flown population density.

$$\mathbf{N = Ac.\ D.\ Fc.\ P}$$

N : **number of victims per million flying hours**
Ac : Lethal surface area (m^2)
D : standard population density (habitants per km^2)
Fc : Corrective density coefficient (>1 for higher density)
P: Crash probability per flying hour

(2) $$\mathbf{N = k.\ D.\ Fc.\ P.\ (MTOW^2 / Sref)^{2/3}}$$

It might be suggested to used the following figures :
Standard population density : D 100 habitants per km^2
Density coef for civil aircraft : Fc 2 (high % of the flight over overpopulated area as terminal zones)
Density coef for military aircraft : Fc 0,3 (high percentage of the flight over low density reserved area)

(2a) $$N = 0{,}028 . D . Fc . P . (MTOW^2 / Sref)^{2/3}$$

4.1 Applications

Fighter :

Ac = 1000 m^2 D = 100 H / km^2 Fc = 0,3 P = 5.10^{-5}

N = 1,5 victims per million hours which corresponds to US Navy figures

B747 :

Ac = 10627 m^2 D = 100 H/ km^2 Fc = 2 P = 3.10^{-7}

N = 0,6 victims per million hours (correlation with statistics to be made).

5. SAFETY OBJECTIVES FOR UAV

Crash probability and so Safety Objectives can be determined using formula (2).

(3) $$P = N. (Sref / MTOW^2)^{2/3} / (k. D. Fc)$$

P: Crash probability per flying hour

N :	Number of victims per million flying hours	**N = 1**
Sref :	Reference Wing surface (m^2)	
K :	Coefficient	**k = 0,028**
MTOW :	Maximum Take off Weight (Mass in kg)	
D :	Standard population density (habitants per km^2)	**D = 100**
Fc :	Corrective density coefficient (>1 for higher density)	**Fc = 1**

(3a) $$P = 0,36. (Sref / MTOW^2)^{2/3}$$

5.1 Applications to large UAV

Application of (3a) equation to large UAV in the defined conditions allows determination of the crash probability.

UAV Type	**Mass** kg	**Wing Loading** kg/m2	**Sref** m2	**Lethal Area** m2	**Crash Probability Objective**
UCAV	**25000**	400	63	1293	**8,E-06**
HALE	**20000**	200	100	702	**1,E-05**
HALE	**8600**	200	43	400	**3,E-05**
MALE	**5700**	100	57	192	**5,E-05**
Fighter	**17000**	400	43	1000	**1,E-05**

Conditions : D = 100 h/km^2 Fc = 1 N =1 victim per million flight hours

6. AIRCRAFT SAFETY OBJECTIVES & CRASH PROBABILITY

By comparing today aircraft safety objectives (as they are defined in the regulations) to the UAV proposed safety objective, we will establish a correspondence between JAR 23 categories and UAV categories.

Safety objectives for civil aircraft are defined by :

JAR ACJ 25-1309 for transport aircraft

FAA AC 23 –1309-1C for commuters, aerobatics & light aircraft

Three main figures have to be considered :

- Aircraft fatal loss which is a figure provided by the statistics. A value which takes into account all conditions of a fatal crash.
- Technical aircraft loss which correspond to the loss of aircraft due all technical errors. The figures is defined by the regulations. This figure vary from 10^{-7} for FAR/JAR 25 to 5.10^{-5} for a FAR 23 light single reciprocating engine aircraft of less than 6000 lbs.
- Catastrophic failure : which correspond to a technical multi failure combinations resulting in a catastrophic failure. It was estimated that on a large aircraft there was 100 of such failures, so the failure value was set as an initial target at 10^{-9}. On a smaller aircraft or UAV the number of such failures will certainly be less than 100.

The following tables provides either for FAR / JAR 25, 23 aircraft, and military aircraft the values corresponding to the 3 types of figures.

AIRCRAFT TYPE		Catastrofic failure	Aircraft loss Technical	Statistics
Military	Combat aircraft	1E-07	1E-05	**5E-05**
JAR 25	Transport a/c, business jets	**1E-09**	1E-07	**3E-07**
JAR 23	Commuters	1E-09	1E-07	**1E-06**
	M > 6000 lbs reciprocating	1E-08	1E-06	**5E-06**
	M < 6000 lbs turbine	1E-07	1E-06	**1E-05**
	M < 6000 lbs reciprocating	**1E-06**	5E-06	**2E-05**

Note : AC 23-1309-1C paragraph 6 t (4) (iii)

Hazardous failure def. : "serious or fatal injury to an occupant other than the flight crew" this means that a fatality is acceptable at 10^{-5}

6.1. UAV safety objectives versus FAR23 safety objectives

Based on the UAV crash probability objective the following table provides an equivalence between the UAV categories and the FAR 23 aircraft categories.

UAV Type	Mass kg	Sref m2	UAV Crash Probability Objective	Equivalent FAR 23 Category	
UCAV	**25000**	63	**8,E-06**	**Commuters**	**1,E-06**
HALE	**20000**	100	**1,E-05**	**M > 6000 lbs Reciprocating**	**5,E-05**
HALE	**8600**	43	**3,E-05**	**M < 6000 lbs Turbine**	**1,E-05**
MALE	**5700**	57	**5,E-05**	**M < 6000 lbs Reciprocating**	**2,E-05**
Fighter	**17000**	43	**1,E-05**	**Today reality**	**5,E-05**

Remark : application of the method to the "combat aircraft" demonstrates that the method is too conservative.

The method apply an additional safety factor of "5" compared to the today design safety factor of the combat aircraft.
The combat aircraft crash probability is around 5.10^{-5}, using the method crash probability will have to be at 1.10^{-5} .

7. CONCLUSIONS

Definition of safety objectives for a UAV is an important task but not an easy one.
The future of UAV will depend of these safety objectives :
Too conservative ones will stop the development of UAV in Europe.
The UAV safety objectives must take into account :

- The protection of populations
- The economics reality to allow a smooth development of the UAV
- The today risk encountered by the populations.
- The safety objectives must be consistent with the safety objectives of all today flying machines not only the objectives of transport civil aircraft but also the objectives of military aircraft as combat aircraft or helicopters.

Using JAR FAR regulations as a guide to define UAV regulations is certainly a good method, nevertheless based on safety objectives the mass categories will have to be redefined.
In a same way limits to single engine mass will have to be increased to reflect the reality of the today combat aircraft.