CLEARED AND GRADED AREA (CGA): CRITICAL ANALYSIS AND PROPOSAL OF A CRITERION FOR GRADING ITS BEARING CAPACITY

Ranieri V.
Assistant professor, Polytechnic University of Bari, Italy – v.ranieri@poliba.it
D'Auria D.
Engineer – ENAC – Italian Civil Aviation Authority – d.dauria@enac.rupa.it

ABSTRACT

The Italian Standards for the Construction and Management of Airports (II edition – Oct. 2003) define the CGA (Cleared and Graded Area) that portion of the runway strip graded and obstacle-less, with well defined dimensions, aimed to decrease damages risks to aircrafts in case of veer-off. At the chapter 3.3.4, the same standards state that the CGA must be jointed together the runway and it must bear the design aircraft that must be able to run on it with its gross weight without suffering any significant damages. […] The bearing capacity of the CGA may gradually decrease outwards in the cross direction to favourite the aircraft stop. In the same standards, the Italian Civil Aviation Authority (ENAC) gives the 12/31/2005 as expiring date to bring into line with it the bearing capacity of the National airports.

Such limitation often generates some uncertainty both to designers and construction contractors on the opportunity and, eventually, on the way of giving this gradual decrease in the bearing capacity. In the paper the authors face this issue through the study of the incidents/accidents for runway lateral excursions occurred from 1980 to 2000 world-wide. The incidents and their consequence have been analyzed in comparison to the lateral excursion range. The risk connected to the over-passing a certain distance from the centreline has been evaluated too. Finally, a criterion is proposed to define the gradation of the CGA bearing capacity.

Keywords: CGA, runway strip, bearing capacity, accident ,runway later excursion, veer-off

1. INTRODUCTION

The ENAC (the Italian Civil Aviation Authority) Standards for Construction and Management of Airports (*ENAC, 2003*) define the runway strip (Chapter 3.4.1) as an area obstacle-less that includes the runway itself and the related stopways.

The aim of the runway strip is to reduce the risk of damages to aircraft running off the runway through the respondence to specific requirements concerning both the cross and longitudinal slopes and the bearing capacity.

In particular, for the instrumental runways, the strip must extend from the centreline (CL) at least for 150 m per side for runways code 3 and 4 and 75 m for the codes 1 or 2.

For the runway strips of code 3 and 4 a Cleared and Graded Area (CGA) must be provided (Chapter 3.4.4 of the Italian Standards) extended at a distance of at least 105 m on each side of the runway CL and its prolongation.

This distance can be reduced at 75 m in the first 150 m of the runway and connected to the 105 m in the first 300 m of runway on both the ends (see figure 1).

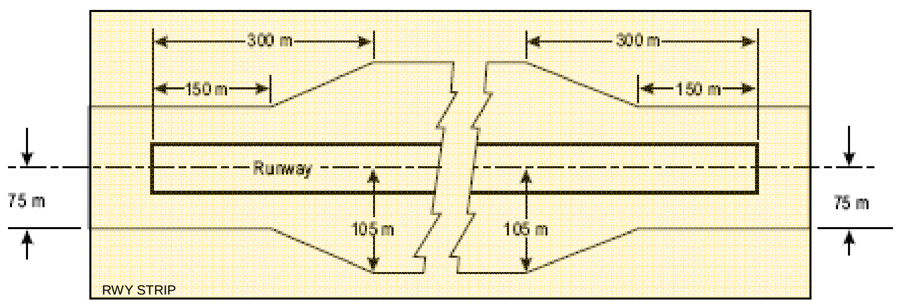

Figure 1 Schematic Representation of the CGA (Source ICAO Annex 14 – "Aerodromes" – *ICAO*, 2004)

The Italian standards gave the 12/31/2005 as the expiring date to set the CGA to the required slopes and bearing capacity.

As for the latter, the following characteristics are given:

- to bear the design aircraft that, with its maximum take-off weight authorised (MTOW), must run on it without any significant damage;
- to favourite the aircraft stop.

To favourite the aircraft stop, the bearing capacity of the CGA can be gradually reduced outwards in the cross direction.

This requirement applies up to a distance from the CL of:

- 75 m for runways code 3 and 4;

- 40 m for runways code 1 and 2;
- 30 m for non-instrumental runways code 1.

To evaluate the bearing capacity, the “risk assessment” procedures adopted by the specific airport should be taken into account.

As for the international contest concerning the CGA, in 2005 Assaeroporti (the Association of the Italian Airport Administrations) made a survey on the European airports and on the biggest Hubs worldwide (*Assaeroporti, 2005*). The survey showed that no standards have been ruled giving the wideness of the intervening strips to decrease the bearing capacity in function of the distance from the runway edge.

The aim of this work is to give a contribution on this matter. It reports the study made to define the width of the CGA strips where gradually decreasing the bearing capacity. In the first analysis the width of each strip can be related to the likelihood that the aircraft stops its run within it. To evaluate this likelihood, the time series of the runway lateral excursions occurred world-wide from 1980 to 2000 has been analyzed.

2. ANALYSIS OF THE RUNWAY LATERAL EXCURSIONS

The Airbus has published on June 2003 (*Airbus, 2003*) the time series of all the incidents/accidents for runway lateral excursions occurred world-wide from 1980 to 2000. For each event the date and place is reported together with aircraft model, flight phase, probable cause, weather condition, damages, number of passengers of injuries and of fatalities and, finally, the runway lateral excursion from the CL.

The time series only deals with lateral excursions and does not take into account of taxiing phase, undershoot landings, overrun landings, use of an incorrect runway or taxiway for landing/take-off and test flights. All narrow and wide body aircrafts have been considered but the Learjet type 24, 25, 35, 60, the RJ-145 and Tupolev Tu-134 and Tu-154 because of the lack of available data. A total of 292 events are reported among which 187 refer to narrow body aircrafts and 105 wide body aircrafts. Of these, only for 202 the veer-off distance is reported, that is useful for the aim of the present study. Table 1 reports the number of these 202 occurrences sorted by the veer-off distance from the centreline.

It can noted that about the 49% of the veered-off aircrafts is retained within the runway (the shoulder included), while about the 11% (22 aircrafts) has passed the CGA limit that is at 105 m from the CL (see figure 2).

Data reported in the time series also show that among the last 22 aircrafts, 16 have stopped beyond the runway strip limit at 150 m from the CL, failing the requirement of favouring the aircraft stop within the runway strip.

Table 1 Number of Incidents/Accidents Sorted by the Distance from the CL at Which the Hulk has been Retained

distance (m)	retained	% retained	Cumulative retained	Cumulative % retained
10	5	2,48%	5	2,48%
20	40	19,80%	45	22,28%
30	53	26,24%	98	48,51%
40	50	24,75%	148	73,27%
50	12	5,94%	160	79,21%
60	10	4,95%	170	84,16%
70	5	2,48%	175	86,63%
80	0	0,00%	175	86,63%
90	1	0,50%	176	87,13%
100	1	0,50%	177	87,62%
105	3	1,49%	180	89,11%
d ≥ 105	22	10,89%	202	100,00%
Total	202	100%		

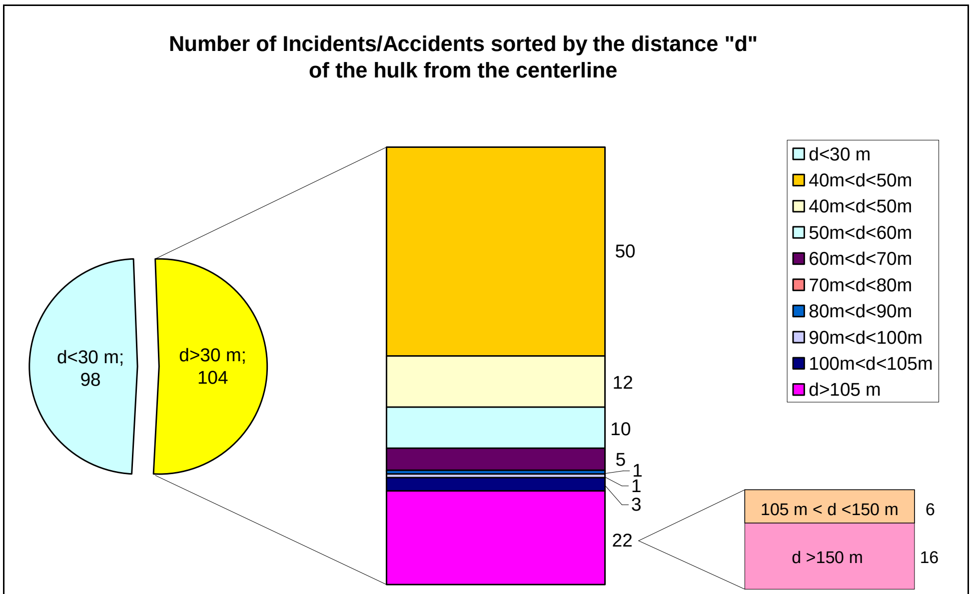

Figure 2 Runway Lateral Excursions Sorted by the Distance from the CL

On analyzing the cumulative frequency of the lateral excursions (see fig. 3), more explicit information can be obtained about the number of aircrafts varying the final position of the hulk from the centreline.

The curve shows that only about the 40% of aircrafts stops in the CGA and about the 44% in the runway strip. It possible to recognise a knee of the frequency curve in correspondence to the 85° percentile that in turn corresponds to a distance of 60 m from the centreline. Thus the 85% of the occurrences is retained within the CGA at a distance of 60 m from the CL. Beyond this limit the frequency distribution decreases meaningfully.

Therefore, in first analysis, the 85° percentile of the occurrences could be set as a threshold to divide the CGA into two different zones: I CGA strip from 30 to 60 m and II CGA strip from 60 to 105 m.

Anyhow, it appears more correct not only to analyze the thresholds within which a certain percentage of aircrafts is retained, but also on the contrary, the thresholds at which a certain percentage of veered-off aircrafts goes through. Concerning this matter, the table 2 shows the number of incidents/accidents sorted by the lateral excursion with the indication of the number and the percentage of the aircrafts that has passed through the given distance d from the CL.

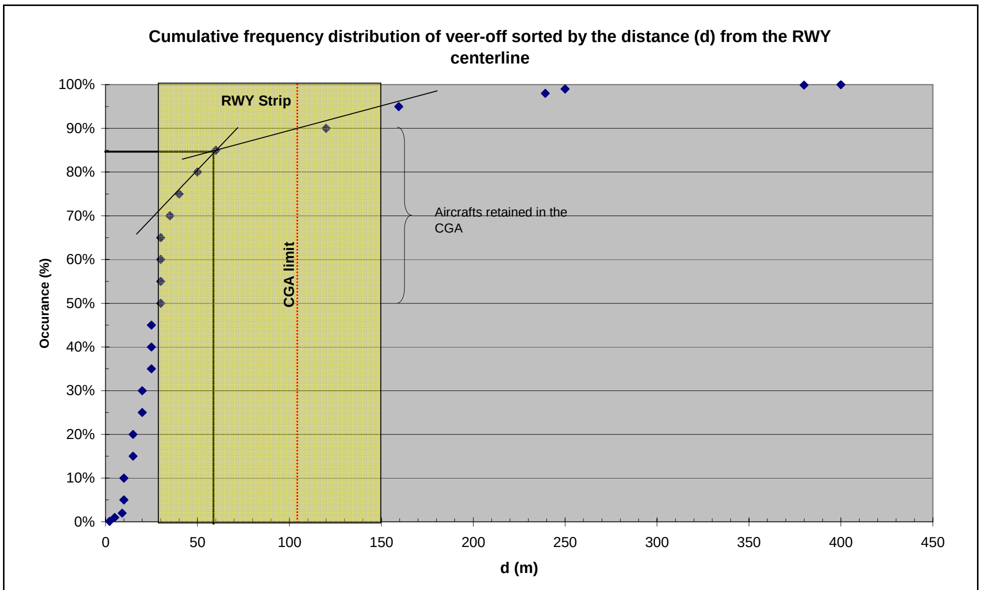

Figure 3 Cumulative frequency distribution of the lateral excursions

Referring to this table, the histogram in figure 4 shows the percentage of the events that have engaged sections of the CGA far and far from the centreline.

Table 2 Number and Percentage of Incidents/Accidents Retained and Passing a Certain Distance d from the Centreline

distance (m)	retained	% retained	Cumulat. retained	Cumulative % retained	Passing aircraft	% passing on total	% passing on total exceeding 30m
30	98	48,51%	98	48,51%	104	51,49%	100,00%
40	50	24,75%	148	73,27%	54	26,73%	51,92%
50	12	5,94%	160	79,21%	42	20,79%	40,38%
60	10	4,95%	170	84,16%	32	15,84%	30,77%
70	5	2,48%	175	86,63%	27	13,37%	25,96%
80	0	0,00%	175	86,63%	27	13,37%	25,96%
90	1	0,50%	176	87,13%	26	12,87%	25,00%
100	1	0,50%	177	87,62%	25	12,38%	24,04%
105	3	1,49%	180	89,11%	22	10,89%	21,15%
d ≥ 105	22	10,89%	202	100,00%			
total	202	100%					

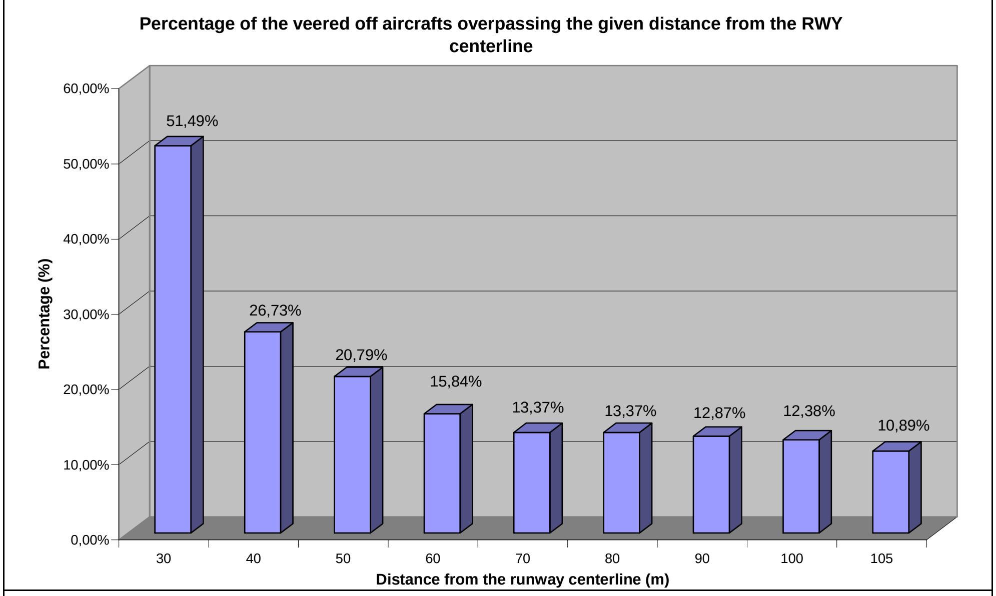

Figure 4 Percentage of Veered-off Aircrafts Passing Through a Given Distance from the Centerline

It is evident that moving away from the runway the number of occurrences decreases with a more than proportional rate. Referring only to the 104 events that have engaged the CGA (82 aircrafts retained and 22 passing), the diagram in figure 5 was plotted. It shows the curve of the relative percentage of the aircrafts passing through a given distance d included between 30 m and 105 m from the CL. Also in this case a knee can be observed at 1/d = 0.022-0.023 that is equal to a distance of 40-45 m from the CL.

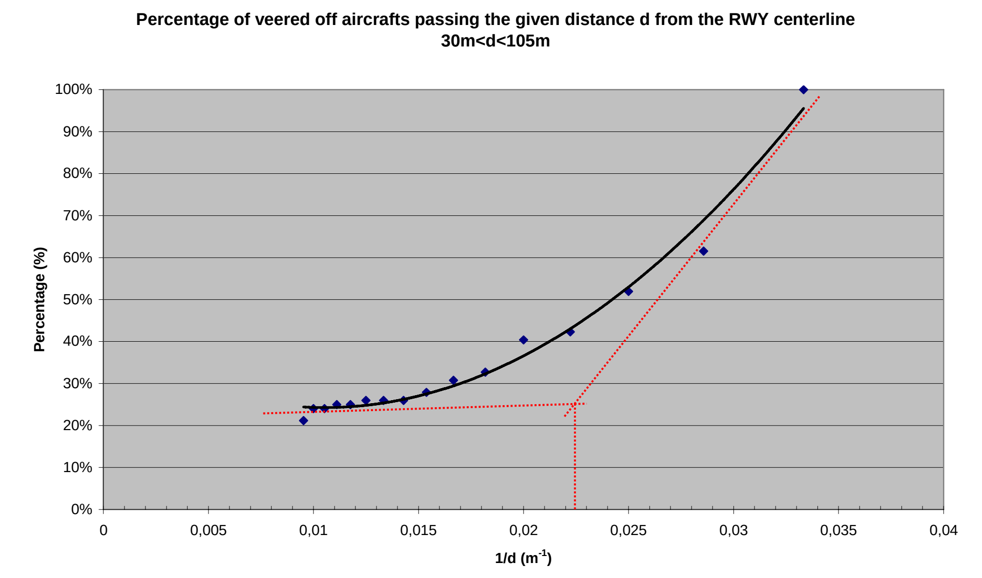

Figure 5 Relative Percentage of Veered-off Aircrafts Passing Through a Given Distance from the Centerline

In the portion of the curve at the left of this limit (for d > 45 m) the percentage of veered-off aircrafts engaging the CGA decreases with a low rate increasing d (decreasing 1/d), while, at the right of the limit (for d < 45 m), the curve shows that the percentage of veered-off aircrafts decreases with a high rate increasing d. This occurrence suggests to set a threshold for the change in the bearing capacity of the CGA at the distance of 45 m from the CL.

Thus, two thresholds could be defined: the first at 45 m from the CL, the second at 60 m. In this way the CGA results divided into 3 strips:

I) 30 m<d<45 m,
II) 45 m<d< 60 m,
III) 60 m<d<105 m.

3. RISK ANALYSIS

Up to this point the analysis refers to the likelihood that in a case of veer-off a certain zone of the CGA is engaged.

Otherwise to each occurrence a consequence is related too. We cannot leave apart this if we wish a complete analysis of the risks related to this kind of events.

Thus a confirmation of the deduction up to here made was searched for through the analysis of the risks associated to the runway lateral excursions reported in the available time series.

The risk is defined as the product between the damages and the occurrence likelihood. Thus, to quantify the risk, the consequences of each event (that include the aircraft damage, the injuries and the fatalities) should be ranked into an interval scale.

To this aim it is useful the tables produced by the UK Civil Aviation Authority *(CAA, 2006)*, where the consequences are associated to a whole numeric value going from 1 to 5 on increasing the severity. The ranking scale adopted is shown in table 3.

Table 3 Scale of the Consequences

Consequence Severity	Description	Scale
Catastrophic	Aircraft incident - loss of life	5
Critical	Major aircraft incident resulting in major injury or aircraft structural damage	4
Serious	Aircraft incident - lost time injury	3
Marginal	"First aid" incident	2
Negligible	Very minor - Little consequence	1

The statistics of the consequences severity calculated for the incidents/accidents reported in the time series are in figure 6 and in table 4. Referring to the distances d from the CL, table 4 reports the mean and the 85° percentile of the consequences severity of all the occurrences for which the given distance d has been overstepped.

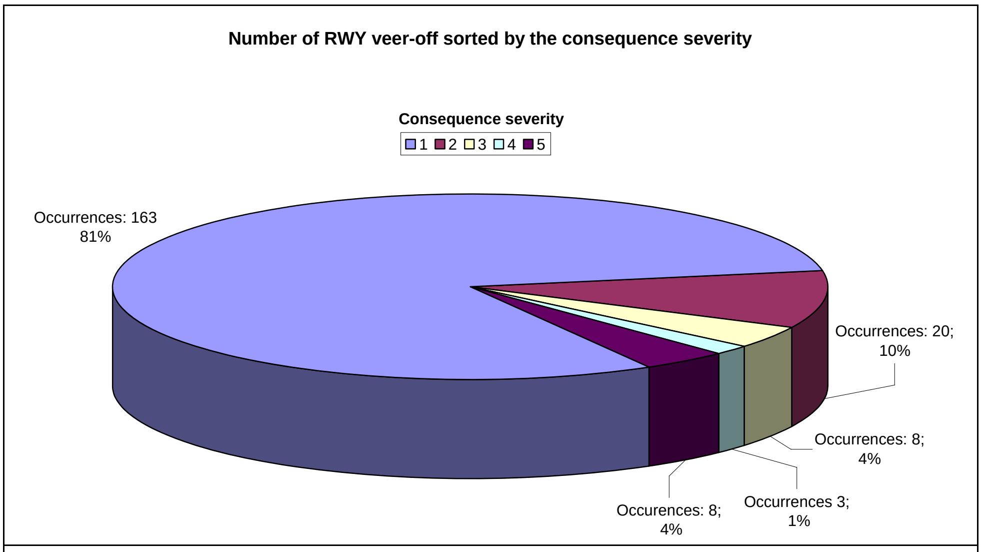

Figure 6 Number of Incidents/Accidents Sorted by the Consequence Severity

Table 4 Mean and 85° percentile of consequence severity of the lateral excursions exceeding the given distance d from the CL

Distance (m)	Consequence (mean)	Consequence (85° percent.)
30	1,663	3
40	2,019	4
50	2,119	4,85
60	2,281	5
70	2,481	5
80	2,481	5
90	2,538	5
100	2,600	5
105	2,591	5

In other words, for a given threshold at the distance d from the centreline, table 4 provides the mean and the 85° percentile of the consequences severity of all the incidents/accidents that have engaged the CGA beyond that threshold. As expected, it is noticeable that on moving far from the runway edge the consequences severity increases whether the mean or the 85° percentile is considered; the increasing rate decreases on increasing the distance up to define an upper limit at the distance of 60-70 m (fig. 7). This is visibly due to the fact that most of the accidents (with consequences severity 5) are also the outmost.

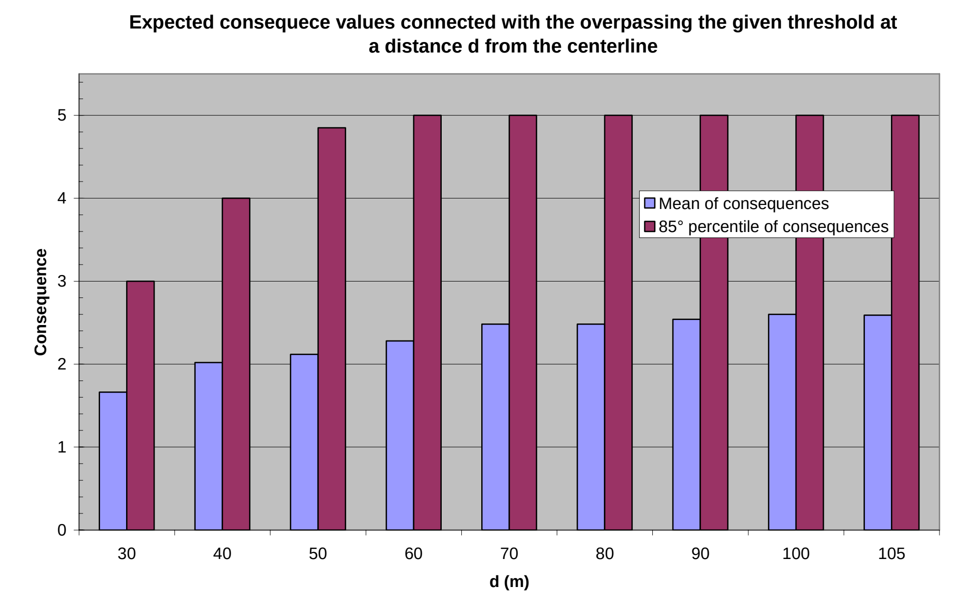

Figure 7 Mean and 85° Percentile of the Consequences of the Occurrence that have Engaged the CGA at the distance d

In first analysis the likelihood that a given threshold is overstepped is equal of the percentage of aircrafts passing the threshold itself in the time series. Thus, in a case of veer-off accident, the risk (intended as the overall damage related to the likelihood of passing a given distance from the centreline) is the product of the mean (or the 85° percentile) of the consequences severity and the corresponding percentage of veered-off aircrafts that in the history have passed the given threshold. Therefore, the scale of the risk is a continuous scale from 0 to 5 where 0 corresponds to likelihood null and 5 corresponds to the likelihood of 100% that a given threshold is overstepped with catastrophic consequences (severity 5). Table 5 reports the risk values so calculated both considering the mean and the 85° percentile of the consequences severity obtained from the time series. Its plot is in figure 8.

The figure shows for both the cases that the risk decreases on increasing d. As for the trend of the curve relative to the mean of consequences, it fast decreases between the threshold at 30m and 60m then to become almost constant in excess of 70 m. As for the risk calculated on the 85° percentile of the consequences, it fast decreases between 30 m and 70 m, with a knee between the thresholds at 40 m and 50 m; in excess of 70 m the risk decreases slightly with an almost constant rate.

Table 5 Risk Related to the Lateral Excursions Exceeding the Given Distance d from the CL

Distance (m)	Consequence (mean)	Consequence (85° percentile)	% passing on total exceeding 30m	Risk (mean)	Risk (85° per.)
30	1,663	3	100,00%	1,663	3,000
40	2,019	4	51,92%	1,048	2,077
50	2,119	4,85	40,38%	0,856	1,959
60	2,281	5	30,77%	0,702	1,538
70	2,481	5	25,96%	0,644	1,298
80	2,481	5	25,96%	0,644	1,298
90	2,538	5	25,00%	0,635	1,250
100	2,600	5	24,04%	0,625	1,202
105	2,591	5	21,15%	0,548	1,058

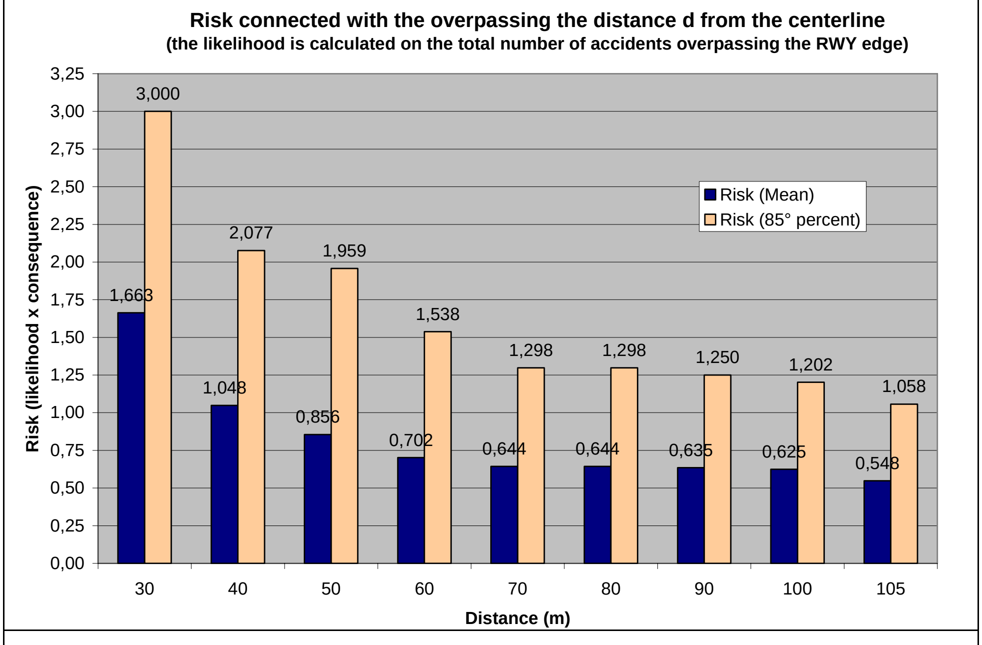

Figure 8 Risk Associated to the Lateral Excursions Exceeding the Given Distance d from the CL

Thus, the trend of the risk seems to confirm the opportunity of setting the thresholds for grading the CGA bearing capacity at 45 m and 60 m from the runway centreline.

This agrees with the ENAC standards that for the runways code 3 and 4 requires that the gradation of the CGA bearing capacity must be applied within the first 75 m from the centerline. It appears to be in agreement also with other international standards, e.g. the UK CAP 168 (*CAA, 2007*) that also recommends avoiding rapid transverse changes in bearing strength.

Introducing other thresholds (e.g. between 60m and 75 m) does not appear to be helpful as, in absence of a strong experimental evidence, this hypothesis seems to be too heavy from the construction point of view.

Thus, according to what above reported, to the quality of the soil in situ and to the weight of the design aircraft, the technicians could refer to these 3 parallel strips to design the gradation of the bearing capacity of the CGA: the first included between 30 m and 45 m from the centreline where the settlements due to the aircraft load are minimal, the second between 45 m and 60 m where the settlement are just about increased, the third between 60 m and 105 m where the settlements are more meaningful to allow the aircraft to stop within the CGA or, at least within the given runway strip.

As for the amount of the allowed settlements in each CGA strip, currently there are no specific indications. The ICAO document # 9157 (*ICAO, 2006*) reports the depth of 15 cm as the limit to which the nose gear might sink without collapsing. Therefore the bearing capacity gradation should take into account this indication e.g. by setting to this value (with regard to the design aircraft weight) the upper limit of the allowed settlements at the outmost CGA strip. The bearing capacity of the inner CGA strips might be set in consequence. Anyhow, this issue is deserving a specific study. Moreover, the opportunity of increasing the 15 cm limit at the outmost runway strip areas also could be investigated.

In fact, the analysis of the veer-off incidents showed that only 32 occurrences (on total of 202) have engaged the CGA beyond 60 m, 22 of which (about the 70%) anyhow have gone beyond the CGA limit with severe consequences (mean value of consequences severity: 2.59). The more, among these 22 aircrafts, 16 also have gone beyond the runway strip limit (at 150 m) encroaching other airfield zones largely with catastrophic consequences (mean: 2.81). Thus, the need of stopping the aircrafts overstepping the 60 m or 105 m threshold appears consistent, eventually even running the risk of a nose gear collapse.

4. CONCLUSIONS

The study presented in these pages aims defining a criterion to act the gradation of the bearing capacity of the CGA through the analysis of the time series of the veer-off incidents/accidents occurred from 1980 to 2000. Firstly, the likelihood that the lateral excursion is retained or is passing through a given distance from the centreline was analyzed. Furthermore the overall damages associated to each occurrence was evaluated through the definition of an interval scale of consequences severity going from 1 to 5. Finally the risk related to each occurrence was evaluated, intended as the product of the mean (or the 85° percentile) of the consequences severity and the corresponding likelihood that the aircraft oversteps a given threshold.

The result is that the principle of favouring the aircraft stop by decreasing the CGA bearing capacity outwards in the cross direction is consistent. To this aim, 3 CGA strips were identified: the first up to 15 m from the runway edge where the settlements due to the aircraft load are minimal, the second from 15 m to 30 m where the settlement are just about increased, the third from 30 m to 75 m where the settlements are more meaningful to allow the aircraft stop within the CGA or, at least within the given runway strip.

Thus, it is evident that for design purposes the general principle of decreasing the bearing capacity in function of the distance from the runway edge is fundamental both to enhance the stop of aircrafts engaging the CGA and to reduce the risk of damages.

Currently national and international standards give no clear indications about the way of enacting the gradation of the CGA bearing capacity so leaving to the designer's judgment the analysis of the problem. The only indication is a recommendation not to exceed the sink of 15 cm to avoid a nose gear collapse. The general criterion indicated by the ENAC standards calls for the CGA being able to bear the design aircraft that must run on it without suffering meaningful damages. Analogue concepts are reported by the ICAO Annex 14. Therefore this issues is deserving a specific in deep examination.

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