

# FLIGHT OPERATIONAL CONSIDERATIONS DURING AIRFIELD DESIGN

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## ABSTRACT

KEY WORDS: Airport Design, Aviation, Safety, Runways.

In the past airfields were designed and built by architectural and engineering companies without due regard and consideration to flight operational requirements. This deficiency was recognized by the International Civil Aviation Organization (ICAO) and the International Federation of Air Line Pilots (IFALPA). Both leading aviation controlling bodies advocated the incorporation of flight operational considerations in the overall airfield layout and pavement design. Pertinent issues to be addressed in the paper include: approach light system design and consideration, aircraft maneuvering area design and construction, taxiway and runway markings, runway skid resistance, runway length and width consideration, runway end safety area (RESA) and safety strip considerations, rapid exit taxiway designs, apron lighting, taxiway design consideration and control over foreign object debris (FOD).

Some case studies (e.g. King Shaka International Airport, OR Tambo International Airport, Lanseria International, Arusha and Mwanza Regional Airports, East London, Nairobi and Kilimanjaro International Airports) will be used to illustrate that by proper consideration to the flight operations factor, these airports could have been planned and designed/upgraded/maintained in a much more efficient and safe manner, that could have ensured an increased availability factor. Major high risk pavement failures have been recorded (asphalt surfacing being blown out and loose stones) by not considering aircraft related factors (jet blast, oil spillages).

## INTRODUCTION

This paper discusses the latest development and design strategy that has been implemented between civil engineering and flight operational specialists. This initiative has developed following the cooperation between International Committee of Airport Authorities (ICAO) and the International Federation of Airline Pilots (IFALPA). The University of Cranfield in the UK presented courses on airport design and runway safety, which was attended by aviation industry specialists. This initiative is succeeding worldwide, with the latest 2012 accident statistics indicating no fatal runway safety accidents for the period.

The drive for enhanced aviation safety in Africa follows a call from international agencies such as ICAO, IATA and IFALPA to introduce programs to radically improve flight safety in the region, which traditionally has the worst flight safety record in the world. The 2012 ICAO Safety Report confirms this trend, with Africa having the worst flight safety record with 7.9 accidents occurring per million departures.

Statistics from the National Transport Safety Board (NTSB) indicate that accidents and fatalities in the taxi and take-off phase of flight, world-wide, account for 24% of the events, while 36% occur in the approach and landing phase.

It became a natural progression to target these phases of flight for the airport design process in Africa, and to pursue an innovative method to combine flight safety requirements with engineering capacity.

### 1. BACKGROUND

In the past airports have been designed with limited flight operational consideration. The airport has been designed by architects, engineers and surveyors, whilst being hounded by financial institutions to keep the project within financial targets and constraints. Developers require the project to be completed on time, according to shareholder concern, with the end product hastily completed and handed over to the airlines and associated operators to use.

The final product is very often flawed with flight safety issues that are often impossible to effectively resolve. The result is an airport upgrade or construction, costing huge sums of money that could have been better designed if the end users had been adequately involved and consulted.

Worldwide it has been established that a fresh new look should be taken at airport planning because of emerging structural changes within the airline industry and the operating environment of airports. Airports, specifically in Africa, have to be designed to facilitate a transformation from a cost recovery organization to actively managed independent commercial entities, utilizing all the components of self-sufficiency, flexibility and originality.

Additional factors that require consideration in the design and operation of airports in Africa include:

- Africa's poor flight safety record and coordinated response to the problem. Airport handling charges, navigational fees and fuel levies increase rapidly with limited re-investment in the aviation industry.
- Global weather change. Drastic changes in weather patterns are emerging within Africa, with the nature and severity of rain, wind and thunderstorms increasing. Traditional surface wind patterns have shifted, making previously correctly oriented runways, now restricted by aircraft crosswind limitations.
- New aircraft types are emerging rapidly in Africa, where the traditional aged second-hand commercial aircraft is being replaced with fuel-efficient, route appropriate aircraft. Aircraft performance and onboard navigational equipment has a huge influence on airport design and approach aids. The joint use of airports in Africa by both civil and military aircraft requires special design consideration.
- Increased legislation and standard operating procedures affect airport design by virtue of aircraft separation minima, wake vortices, security standards and environmental consideration.
- New technologies are now available for the automated lighting and control of taxiing aircraft, detection of foreign objects on airfields and prevention of runway incursions.
- Africa requires unique solutions to aviation and airport related operations and facilities. It is unwise to hoist European based generic solutions and designs onto African projects, as the solution rarely caters for the cultural, aesthetic or unique operational requirements.

Practical operating and engineering exposure within Africa has resulted in the generation of simple solutions. Simple not because of the nature of the problem, but simple solutions that by their very nature would enhance continuity and consistency, which has been a negative factor within African aviation in the past.

## 2. FLIGHT OPERATIONAL CONSIDERATION

The following flight operational factors should be considered during the initial design or upgrade of an airfield. Should these design considerations and operational requirements be neglected, significant operational problems would result, possibly becoming contributory factors in aircraft operating incidents or accidents.

### 2.1. Approach light systems

Approach Light Systems (ALS) provide the basic means to transition from Instrument Meteorological Conditions (IMC) to Visual Meteorological Conditions (VMC) for landing.

Operational requirements dictate the sophistication and configuration of the approach light system for the particular runway. ALS usually serves a runway that has an instrument approach procedure associated with it.

Instrument approaches are either classified as precision or non-precision. The precision approach is defined as that which has an electronic glide path, which provides glide slope information to operating crew, whereas the non-precision approach provides no electronic glide slope information.

The required minimum visibility for instrument approaches is influenced by the presence and type of approach lighting system. In Nairobi for example, where a High Intensity Runway Light System (HIALS) is fitted, a precision ILS approach onto Runway 06 for a category C or D aircraft, requires a minimum visibility with a full approach light system of 550m. With no approach lights this minimum visibility increases to 1200m. A non-precision approach (NDB) onto the same runway with the same category aircraft, requires a minimum visibility with full approach lights of 1400m. With no approach lights this minimum visibility increases to 2100m.

The transition from IMC flight to VMC flight is a gradual progression of increased visibility, which can be reduced by intermittent rain and cloud or fog patches.

When flying an ILS approach for example down to the standard minima of 200ft and 550m, the aircraft will be 1172m from the runway threshold when reaching operating minima on a 3 degree glide slope.

If that runway was fitted with a standard 900m precision category 1 lighting system, the approaching aircraft would be 272m, ground distance, from the first elements of the approach light system at operating minima, and likely to have them in sight. (ICAO Annex 14 ATTA-13).

It is important to note that the pilot cannot continue the approach below decision height (DH) unless visual reference to certain identifiable airfield and runway lighting is made. Elements of the approach light system constitute such reference points.

The requirements for the installation of ALS is contained in ICAO Annex 14 Section 5.3.4 where it is recommended to have a simple approach light system installed for no-precision approaches and where physically practicable a precision approach light system for Category 1 approaches. Category 2 and 3 approaches require a specific lighting system as specified in ICAO Annex 14 Section 5.3.4.22.

It is interesting to note that the new published RNAV (GNSS) approaches conducted solely with reference to on board aircraft navigational equipment, is classified as a non-precision approach. For example at Kilimanjaro International an RNAV (GNSS) approach onto runway 09 has a published operating minima for a Category D aircraft of 3300ft or 368ft AGL, and 1600m visibility. If the approach light system was not installed or operative, the minimum required visibility increases to 2000m.

In Africa where many non-precision approaches are conducted onto runways with no approach light systems installed, it is recommended to local authorities to install at least a simple 420m approach light system. This would provide both guidance and orientation at low levels at night, or whilst operating in the day in heavy rain and associated reduced visibility.

### Skid resistance of runway surfaces

ICAO Annexure 14 provide clear recommendations on the skid resistance and surface texture of runways with a new surface layer (0.74\*), a maintenance level (0.53\*) and a minimum level (0.43\*). (Note \*Grip tester at 65km/h)

The Airports Company of South Africa (ACSA) made a decision in the interest of aviation safety to comply with the ICAO guidelines with respect to friction and surface texture criteria. On recent runway projects a friction criteria of 0.74 (Grip tester at 65/km/h) and a surface texture of 1mm was set as a design criteria.

In South Africa few mixes are able to achieve these very strict criteria. These mixes include Ultra-Thin Friction Courses (UTFC) and Bitumen Rubber Semi Open Graded Mixes (BRASO). A popular option in many countries such as Australia and England is to cut grooves into a standard asphalt surface in order to achieve the ICAO friction and texture depth requirements. This latter option to groove the surface generally reduces the life of an asphalt layer up to 50%.

The use of UTFC mixes gain popularity in Southern Africa and many runways have been rehabilitated with this type of mix. However, this is a very sensitive and difficult mix to design and construct and incorrect practices will result in premature raveling after construction as well as a reduction of the design life. The design life of a UTFC is between 7 and 8 years and if not rehabilitated in time, major raveling can be experienced, which is extremely dangerous for aircraft.

BRASO mixes (successfully constructed at East London Airport in 2013) may not always be able to achieve the design criteria and destructive water cutting may be required (e.g. Cape Town International Airport in 2013).

However, from a flight operational perspective, the absolute level of 0.74 is not significant and reduction to a design level of 0.65 would have a minor risk on the safe operation of aircraft. However, factors that are critical and pose major operational risks when landing under severe weather conditions and emergency situations, is a consistent surface texture across the length and width of a runway. At many airports this is not the case (e.g. Cape Town)

## Runway and RESA geometrical considerations

The runway length will be determined by operational criteria and the performance characteristics of the relevant aircraft planned to operate into the airport. This would be determined by operational criteria as defined in ICAO Annex 14, Sect. 3.1.7 or planned in conjunction with ICAO Annex 14 Sect. 3.1.9 with regard to the inclusion of a stop-way or clearway. Runway width is determined by reference to the Aerodrome Design Manual (ICAO Doc 9157 Part 1) and is influenced by operating type of aircraft and the nature of the approach, instrument or non-instrument.

Runway End Safety Areas (RESAs) are to be provided at the end of a runway strip to a distance of at least 90m, or 240m where the Aerodrome reference code number is either 3 or 4 (ICAO Annex 14 Sect 3.5.2 and 3.5.3) The width of the RESA shall be at least twice that of the associated runway. RESA surfaces should be prepared or constructed to reduce the risk of damage to an aircraft that overshoots or undershoots a runway and enhance aircraft deceleration, whilst providing a surface to facilitate the movement of rescue and fire fighting vehicles. Guidance on the strength of a RESA is contained in ICAO Doc 9157 Part 1.

An EMAS (Engineered Material Arresting System) has been installed on the overrun areas of 30 major North American airports with considerable success. These systems are recommended where there is rapidly sloping terrain prior to the RESA. The EMAS system incorporates the use of hardened foam blocks that collapse when an aircraft overruns and safely decelerates the aircraft on a controlled surface. This system was recommended for the new runway 06/24 at Lanseria, due to rapidly sloping terrain prior to the RESA defined area.

## 2.2. Airfield pavement light systems

Taxiway centre line guidance shall be provided on runway exit taxiways, taxiways and de-icing facilities especially when Runway Visual Range (RVR) conditions of less than 350m could be expected. These lights do not have to be provided if traffic is light and taxiway edge lights and center line markings provide adequate guidance. (ICAO Annex 14 Sect. 5.3.16).

Taxiway center line lights should be provided on a taxiway intended for use at night in an RVR of 350m or less and where there is a complex intersection of taxiways that may be confusing (ICAO Annex 14 Sect. 5.3.16.2).

At Heathrow Airport (UK), the taxiway center line lighting is automatic and guides each aircraft individually to a parking bay or runway departure point, posting red 'do not enter' lights or temporary red stop bar lights to prevent runway incursions or collisions.

This center line guidance lighting system would have prevented the British Airways Boeing 747-400 accident at OR Tambo International Airport (ORTIA) Johannesburg, where the aircraft taxied up the incorrect taxiway en-route to the departure runway and collided with a building. This seemingly innocuous accident could have had tragic consequences.

This taxiway lighting system should have been considered at ORTIA during the design and upgrade of the airport, because the airport operates in low visibility conditions, and has to cross arriving aircraft from runway 03R over the other active runway, 03L.

### Airfield pavement paint markings

White threshold white markers are required to be painted at the threshold of paved instrument runways (ICAO Annex 14 Sect 5.2.4). These markers are positioned 6m from the threshold and on a 60m wide runway such as at King Shaka International Airport (FALE) there would be 16 stripes 30m long and 1.8m wide. These markers have been painted in solid white as directed.

If one examines the geography of the threshold of runway 06, it can be observed that a taxiway enters the runway at this point. A landing aircraft on runway 24 exiting at the end via the taxiway turns right, first down the lateral runway slope, then down a taxiway to the apron. During rainy conditions the 90 degree turn right, downhill across the solid white painted runway markers is slippery and pilots have complained of lack of traction at this point.

A solution that could have been pre-planned, was to paint the runway threshold markers in a series of longitudinal stripes in order to reduce the painted surface and improve traction on the unpainted asphalt (ICAO Annex 14 Sect 5.2.1.4 Note 3).

At the same airport, the taxiway centre line markings are yellow and 150mm wide as directed in ICAO Annex 14 Sect 5.2.8. These taxiway centre line markers are virtually invisible at night and in the rain when taxiing onto the concrete apron with strong overhead apron lighting.

With prior consultation these lines should have been 300mm wide, outlined in black on the concrete apron and also have centre line guidance to the parking bay.

### 2.3. High Speed Runway Exit Taxiway Designs

The optimal locations of rapid exit taxiways along a runway are based on several criteria described in the Aerodrome Design Manual, ICAO Doc 9157 Part 2. In addition, valuable reference data is also available in the US Department of Transportation Advisory Circular No. AC 150/5300-13A.

The critical issue is the positioning of the high speed exit from the landing threshold. The positioning will depend to a large degree on the range of aircraft types that would be targeted for rapid runway exiting. Table 4-9 of the US Advisory Circular indicates that large aircraft from between 12,500lbs (5640kg) to 300,000lbs (136,000kg) would exit a high speed runway exit positioned 1372m from the threshold on 51% of landings and would exit from 1981m on 100% of landings. This percentage would be increased in wet weather.

High speed runway exit taxiways aim to increase the runway occupancy rate and as a result are designed into high density traffic runways.

Consulting experience in Africa on smaller regional airports with a total runway length of 1800m, has shown airport designers incorporating expensive high speed runway exits for small aircraft, 12,500lbs (5640kg) or less, where the 100% efficiency exit rate occurs 1372m from landing threshold. These high speed exits are incorrectly positioned as shown in Figure 4-26 of the US Advisory Circular and cost the client much more than a conventional 90 degree runway exit taxiway. This has occurred at the planned new Arusha Regional Airport in Tanzania, where high speed runway exits were planned by a European company and subsequently removed following a consultation process.

### 2.4. Foreign Object and Debris (FOD) risk on runways

Incidents arising from Foreign Objects and Debris (FOD) on runways cost the aviation industry US\$4 billion in aircraft repairs and maintenance annually. Flight delays and accident claims add to this cost. FOD includes a wide range of materials, such as a part fallen off from an aircraft, a detached runway light fitting, building materials, rocks and wildlife. Dead birds struck by arriving and departing aircraft and lying on the runway cause significant damage to aircraft engines. Aircraft tyre treads often separate from the wheel and litter the runway. The Air France Concorde crash in July 2000, which claimed 113 lives, reinforces the need for real-time, automated FOD detection.

Currently, airport authorities conduct daily manual runway sweeps to remove FOD. This tedious and error-prone process can be automated by a system called iFerret. iFerret is able to detect and classify foreign objects, as well as accurately define their position. This system features self-calibrating cameras, automated scene analysis and scan resolution for different object sizes.

This system would be ideal for airports with long runways, such as ORTIA, where aircraft True Air Speeds (TAS) are high on departure for long intercontinental flights, at a high elevation airfield.



## 2.5. Obstacle limitations

It is essential that the airspace around aerodromes be maintained free from obstacles, so as to permit the intended aircraft operations at the aerodrome to be conducted in a safe manner. This would prevent the aerodrome becoming unusable by the growth of obstacles in the vicinity of the aerodrome.

Obstacles which penetrate the obstacle limitation surfaces defined in ICAO Annex 14 Chapter 4, may in certain circumstances cause an increase in the obstacle clearance height/altitude for a specific instrument approach procedure, or have an effect on flight procedure design which is contained PANS-OPS, Doc 8168.

Obstacle identification is an important feature of airfield safety audits and a possible obstacle was detected at the new Mwanza Regional Airport in Tanzania, where a new 21m high ATC tower was to be constructed on a nearby hill. This obstacle could possibly have penetrated the Inner Horizontal height of 45m and 4500m radius for Code 3 and 4 aircraft.

## 2.6. Military design issues

In Africa there are many civil airfields that share their facilities with the military. Military aircraft have specific unique operating procedures which must be incorporated in the airfield design of runways and taxiways. This is particularly important where military fighter and ground attack aircraft will operate with live weapons, which require consideration and the incorporation of specific operating procedures.

At Mwanza Regional Airport in Tanzania, it was essential to interface with the military wing, and redesign the taxiway system to facilitate live weapon arming and last minute adjustment prior to take-off. If this change had not been effected, serious delays to civil traffic would result. In addition the specific military aircraft performance must be considered, not only on the runway, but integrated with civil ATC procedures. The integration and planning of military and civil security procedures must be considered in the design of aprons and associated access control measures.

## CASE STUDIES

The section provides some valuable lessons and the application of flight operational principles on various airport designs, its impact on safety, operational efficiency and financial consideration.

### 2.7. King Shaka International Airport FALE

The land for King Shaka International Airport had been procured many years prior to the commencement of the construction process. When this started, it was a requirement to complete the process prior to the Football World-Cup competition in 2010. As a result many processes were hurried and insufficient consideration was given to critical operational issues.

The first issue that was overlooked was the installation of the approach light system onto runway 24. The final result was that the approach light system and the toll-plaza on the N2 freeway are in conflict and pose a risk to flight safety.

ICAO Annex 14 Sect 5.3.1.3 recommends that “a non-aeronautical ground light which by reason of its intensity, configuration or colour, might prevent, or cause confusion in the clear interpretation of aeronautical ground lights should be extinguished, screened or otherwise modified so as to eliminate such a possibility.” In particular, attention should be directed to a non-aeronautical ground light visible from the air within the areas described as an Instrument runway, code 4. No non-aeronautical ground light should be positioned within the area before the threshold and beyond the end of the runway extending at least 4500m in length from the threshold and runway end and 750m either side of the extended runway centre line in width.

The toll plaza is situated within this zone 1200m from the runway 24 threshold and 190m to the East of the extended runway centre line. The Aerodrome reference chart for FALE contains a warning to pilots to exercise extreme caution when approaching runway 24 due to the toll gate lights can be mistaken for runway landing lights.

This issue highlights a failure in the planning stage to accurately assess the flight operational implications for locating the approach light system so close to a toll plaza. To remedy this mistake in planning is virtually impossible, with the result that the airport has a built in flight safety problem.

- A secondary poor planning issue was the design of the International apron area that effectively can only handle one wide-body jet at a time, as well as the apron being a dead end with only one taxi-way leading in and out of the apron. If two wide-body jets are positioned as planned against the terminal building, the aircraft parked to the south-west would be unable to push back and start, due to the presence of the elevated terminal access road. If a flight operations consultant had been involved, the practical implications of the design could have been addressed.

The runway surface was constructed with a Stone Mastic Asphalt (SMA) mainly due to good performance of the mix on other airports worldwide. However, during final friction testing it was found that the runway surface did not meet the ICAO recommendation and destructive water cutting was required to achieve the value. This raised the question on how significant the absolute value of 0.74 is, as a slightly lower value will have a minor impact on flight safety, whereas the water cutting damaged the SMA mix by removing the protective binder film resulting in a reduction in life and a potential risk of raveling failures.

## 2.8. East London Airport

The runway surface at East London airport is a critical issue as the longest runway, runway 11/29 is only 6362ft long and 151ft wide. Poor weather including heavy rain, strong crosswinds and poor visibility are features of this airport. Medium size jet aircraft such as the Airbus A319/320 and Boeing 737-800 use this runway. It is essential that the runway surface provides optimal braking for these aircraft. It has been observed by operating crews that the longitudinal runway slope at the threshold of runway 29 is excessive. The required runway slope limitations are laid down in ICAO Annex 14 Para 3.1.13.

Runway slopes, both longitudinal and transverse, should be examined and discussed with operational aviation consultants prior to construction. This would include the detection of possible obstructions that could detract from the runways operational capacity.

## 2.9. Lanseria Airport

A good example of the coordination between flight operational consultants and civil engineers took place prior to the construction of the new runway 06/24 at Lanseria International Airport. Planning the new facility, all operational factors affecting the new runway and its construction were considered. This included:

- Runway surface determination.
- Runway width consideration. It was determined that a 45m runway was the optimal width in order to accommodate medium jets on an ILS approach.
- Runway approach lighting, the inclusion of a simple approach light system.
- Determining the airport designator as Code 3C with the design capacity to increase to 3D by adding two 7,5m runway shoulders.
- Runway and taxiway markings discussed and defined.
- Appropriate runway lighting determined
- A programme was instituted to coordinate the construction and certification of the new runway with the South African CAA.
- Runway and taxiway drainage was defined, including optimal transverse and longitudinal slopes.
- A flight safety programme was devised to coordinate the new runway construction in pace with the daily operation on the old runway. The new runway was positioned parallel to the existing facility.
- RESA dimensions determined and an SMA overrun surface recommended.
- ILS installation requirements determined and coordinated with construction.
- Required official documentation determined.

The entire programme of planning, construction and operational implementation was successfully completed and illustrated the efficiency of coordinating flight operational experts during the planning, construction and implementation phase.

## 3. CONCLUSION

Lithon have determined and defined an area for improved efficiency and flight safety improvement and have designed methods to coordinate flight operational considerations and engineering technique to the benefit of aviation safety in Africa. The involvement and cooperation of flight operational experts in the planning, construction and implementation phases of airport design, result in significant financial benefits, including the improvement of flight safety margins. Significant savings in airport construction costs have been achieved by installing appropriate and effective installations, without reducing flight safety margins.

While the use of UTFC and BRASO mixes has been used very successfully on South African airport runways to achieve the ICAO skid resistance criteria, the paper has highlighted the risks associated with the use of these type of mixes. In particular UTFC when not optimally designed, monitored during construction and timeously rehabilitated at the end of its design life, as it can be a major risk factor in aviation safety due to the mode of failure (both premature construction related and ultimately at the end of design life).

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