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FOR THE SAFETY OF AIR NAVIGATION

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OPERATIONAL EVALUATION OF PROTOTYPE TAXIWAY RUMBLE FEATURES

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Contents

EXECUTIVE SUMMARY

In response to Stakeholder requests, Eurocontrol conducted an operational evaluation to assess the potential of a 'Taxiway Rumble Feature' as an additional runway incursion prevention measure.

This report describes the second phase of a project to study the possible introduction of taxiway rumble features on civil airports. The project was commissioned by EUROCONTROL in support of the Runway Safety project. It forms part of ongoing work to develop strategies to support operational staff on the manoeuvring area.

The task involved the 'Operational Evaluation' (installation, monitoring and evaluation) of a prototype rumble feature on an operational taxiway at a civil airport.

Feedback from users of the Rumble Feature (i.e. pilots and airside drivers) was collected over a three month period of operational evaluation at Southampton International Airport.

Based on the feedback of the users, it was concluded that a tactile stimulus in the form of vibration was discernible by pilots and airside drivers. However, the stimulus was not recognised uniformly or unambiguously, and the feedback indicated no clear benefit in the assistance of situational awareness.

Typical comments included:

> "Not possible to differentiate between feature and taxiway conditions regularly encountered e.g. metal plates, taxiway lights etc."
>
> "Not possible to differentiate between rough tarmac and rumble strip."
>
> "Any use of permanent feature will not work because it will always have to be passed anyway when cleared. Simply use stop bars everyone knows what they mean."
>
> "Visual indicators are much better."

A significant proportion of responses indicated that the vibration was viewed as a distraction and that users would seek to 'tune out' the alerting stimulus.

It has been concluded that the Rumble Feature is ineffective as a runway incursion prevention measure because of the expected tendency for users to mitigate and thus avoid the alerting vibration.

There was also a concern that, if pilots were to adjust their speed to minimise the vibration from the rumble feature, it could be a distraction from the operation of the aircraft.

CHAPTER 1 – Introduction

This report describes the feasibility of using 'Taxiway Rumble Features' on civil airports as a runway incursion prevention measure.

The project was commissioned by EUROCONTROL in support of the Runway Safety project. It forms part of ongoing work to develop strategies to support operational staff on the manoeuvring area to improve runway safety.

The first phase of the project consisted of a desk study of the rumble feature concept and consultation with stakeholders, culminating in a Feasibility of Concept report (Reference 1) and a request to conduct an operational trial. The second phase of the project (the 'Operational Evaluation') consisted of the installation, monitoring and evaluation of a prototype rumble feature on an operational taxiway at a civil airport.

The objectives of the project and the Operational Evaluation phase, and the Key Success Factors (KSF) used to evaluate the findings of the Operational Evaluation, are set out below.

Chapter 2 summarises the key points from the first study phase, and the Feasibility of Concept report.

Chapter 3 describes how the Operational Evaluation stage was carried out, including the physical attributes and location of the prototype installation and the arrangements for briefing stakeholders and managing risks associated with the project.

Chapter 4 summarises the feedback responses received from stakeholders during the trial, and analyses these in terms of the agreed KSF.

Chapter 5 summarises the Conclusions of the study.

1.1 Objectives

1.1.1 Project Objectives

This study aimed to determine the feasibility of implementing rumble features on taxiways, as an additional safety net to help prevent runway incursions.

The objective of the project was to study the possible introduction of a tangible indication of entering a runway through the use of raised or grooved patterns on the taxiways leading to

the runway as a measure to prevent runway incursions. The feature was intended to give a physical indication of entering a runway through vibration. This vibration had to be acceptable for pilots, drivers and passengers, and its meaning correctly understood, as well as being compatible with all types of vehicle and aircraft.

This item of infrastructure is known by the generic description ‘rumble feature’.

1.1.2 Objectives for Operational Evaluation

The objectives of the second phase of the project were to carry out and assess an Operational Evaluation of the Rumble Feature concept. as follows:

- Install a prototype taxiway rumble feature safely in an appropriate location on an operational airport, maintain it in a safe condition during the evaluation period, and reinstate the taxiway to its original condition at the end of this period;
- Observe the effect of the rumble feature on situational awareness of taxiway users;
- Obtain feedback from taxiway users and other stakeholders on any other effects of the vibration induced by the rumble feature;
- Assess the effectiveness of the rumble feature as an additional safety device, and make recommendations regarding further/wider application of the rumble feature concept.

1.1.3 Scope

A rumble feature was considered as a possible warning in locations where a potential for a runway incursion may be foreseen, including a displaced threshold or any runway entrance.

1.1.4 Constraints

The following limitations on the potential application of taxiway rumble features were established, and may be taken into account in the assessment of the Operational Evaluation

- The function of a taxiway rumble feature was intended to be to provide a warning, not to serve as a speed control.
- A rumble feature could have served as a supplement to, but NOT a replacement for, existing visual cues that warn a runway is ahead (e.g. paint markings, runway guard bar lights).

1.2 Key Success Factors

The following Key Success Factors (KSF) were identified, at the beginning of this phase of the project, as a basis on which the results of the Operational Evaluation has been assessed:

Recognition: Initial feedback from pilots and drivers of different aircraft/vehicle types suggests or indicates (i.e. confirms) that the tactile stimulus produced by the induced vibration is discernible and recognisable, and assists situational awareness.

Repeatability: Feedback later in the Operational Evaluation indicates that the tactile stimulus is still recognised and the contribution to situational awareness is not negated by familiarity or deterioration of the rumble feature profile.

Compatibility: Feedback from aircraft operators confirms that operation across a rumble feature does not have any negative effects on aircraft (e.g. airframes, undercarriage etc) or vehicles (inc. Emergency vehicles).

Throughput: Feedback from all participating Operational Evaluation parties (including Aircraft Operators, ATC and Airport Operations) suggests no negative effects on air traffic safety, throughput or ground operations.

The evaluation had to take account of any secondary factors which might skew the data. For example, repeatability (KSF(ii)) might be affected both by reduced awareness (due to growing familiarity with the induced vibration) and by a reduction in the level of vibration (due to deterioration of the profile of the particular material used to form the rumble strip for the Operational Evaluation).

CHAPTER 2 – The Rumble Feature Concept

2.1 Feasibility of Concept

Stakeholders requested the development of the rumble feature concept as an aid to the prevention of runway incursions. On the basis of a study and stakeholder consultation, validation of the physical characteristics of a rumble feature was organised through the operational evaluation of a temporary (prototype) installation at a representative airport.

2.2 Physical Characteristics

The study was based on the premise that proposals for a taxiway rumble feature must be compliant with current ICAO requirements. A review of regulatory, design and construction standards governing airport infrastructure was carried out. This identified no relevant 'permissible' criteria, but noted two key performance requirements for taxiways which must be satisfied to comply with ICAO Annex 14 (Reference 2):

- The surface irregularities introduced to create the feature must not cause damage to aircraft or vehicles.
- It must not affect the drainage of water from the taxiway so as to impair braking action.

The criteria relating to the construction of airfield pavements provided no guidance that might be relevant to the dimensions for ridges or grooves on a taxiway surface. However it was noted that the projection of typical taxiway light fittings in current use was in the order of 10mm – 13mm, and that these were trafficked by aircraft without damage. The following dimensional limitations were proposed:

- The vertical dimension (i.e. height or depth) of ridge or groove forming a rumble feature should not exceed 13mm, by analogy to the height of AGL lights.

- The profile of a rumble feature should not present a vertical face greater than 6mm to a wheel, corresponding to the maximum irregularity permitted for joints in new concrete pavements in Annex 14 (Reference 2).

It was recognised that the nature of the vibration would vary according to the taxi speed of the aircraft. A design assumption of a 10 knot taxi speed was proposed, and agreed by stakeholders.

Design criteria for the profile and spacing of a prototype rumble feature was proposed, based on the intent to provide an alerting vibration over a short duration (approximately 0.5 seconds at the design taxi speed) in locations close to a runway holding position.

The location of a rumble feature should be suitable to provide an alert prior to a runway holding position, so it should be positioned far enough from the RHP that existing visual safety nets (markings, lights and signs) would still be visible.

For further detail see Annex 1.

2.3 Stakeholder Requirements

Operational implications were examined in consultation with stakeholders before and during a Stakeholder Workshop on 26 June 2008. Potential issues identified during the study were:

- The rumble feature must not restrict runway throughput at an airport.
- Cautionary vibration to traffic leaving a runway (where a taxiway may be used in either direction depending on the direction of the active runway) would be undesirable.
- Rumble features should not create an onerous maintenance requirement for pavements, lights, aircraft or vehicles.
- A taxiway rumble feature must be identifiable to aerodrome users (e.g. by pavement marking, colour etc) and would require notification by NOTAM and inclusion in aerodrome charts published in the AIP.
- The characteristics of a rumble feature must comply with the requirements of the relevant national regulatory authority.
- The Rumble Feature must continue to get the attention of the pilot or driver effectively after repeated uses.

CHAPTER 3 – Operational Evaluation of Prototype

In response to Stakeholder request, following the Feasibility of Concept Report and the Stakeholder Workshop, Eurocontrol conducted an operational evaluation to assess the potential of a taxiway rumble feature as an additional runway incursion prevention measure.

3.1 Location for Evaluation

The Operational Evaluation, was planned at an appropriate location for the evaluation feature in consultation with airport stakeholders prior to implementation.

A suitable location for the rumble feature evaluation would depend significantly on the configuration of the airport. The preferred location would be a main runway entry point, or an entry point prior to a displaced threshold. A location serving primarily as a runway exit, e.g. a Rapid Exit Taxiway, would not be used. A location which could be by-passed, by traffic entering the runway at a different point, might be useful for comparison purposes.

Southampton International Airport Ltd (SIAL) agreed to host the Operational Evaluation.

3.1.1 Airport Characteristics

The following characteristics were noted at the time of the evaluation:

Air traffic at Southampton International Airport consisted primarily of scheduled commercial movements of Code C aircraft; a limited proportion of movements were made by smaller GA aircraft.

Southampton International Airport (EGHI) has a single runway aligned 02-20. The principal taxiway system joins the runway at entries A1 (used by 02 Departures) and B1 (used by 20 Departures) and does not extend to the ends of the runway. Backtracking operations are necessary, particularly for Runway 20 departures. Movements are split approximately 55% Runway 20, 45% Runway 02.

Conditional clearances are not used.

At the time of the evaluation, the Runway Holding Positions were denoted by pavement markings, runway guard lights (wig-wags) and illuminated signs but runway guard bar lights were not installed.

Two runway incursions (both involving non-based GA aircraft) were recorded at the airport during 2008.

3.1.2 Location of Rumble Feature

The agreed location for an Operational Evaluation Rumble Feature was located on Taxiway A prior to Hold A1, one of the main entry points. This position would be trafficked by Runway 02 departures, i.e. approximately 45% of departures, providing a substantial potential sample of movements for gathering feedback.

Although Runway 02 arrivals (45%) would vacate at B1, arrivals on Runway 20 may need to vacate at A1. A proportion of arrivals would thus traffic the Operational Evaluation feature after vacating the runway. Data collection therefore needed to discriminate between arriving and departing aircraft, to assess the effects of the vibration stimulus in these circumstances

The particular location for the evaluation feature was confirmed in consultation with airport stakeholders before implementation. To demonstrate the nature of the proposal to stakeholders, a trial example of the proposed rumble feature was installed on a non-operational pavement some weeks before the installation on the active taxiway.

3.2 Design of Prototype

3.2.1 Physical Characteristics

The physical characteristics of the rumble features for Operational Evaluation were generally as discussed with stakeholders during the first phase of the project (see Annex 1). Some details were reviewed following discussions with a specialist contractor on the practicalities of construction, and to take account of comments by the Regulator (UKCAA/SRG).

The key characteristics were:

- Ridges were formed across the taxiway by building up the required profile with hot-applied thermoplastic marking material. The ridges were designed to be removed at the end of the period of the Operational Evaluation, leaving the original taxiway surface.
- Each feature consisted of 4 transverse ridges across the taxiway, each 300mm wide with 500mm gaps (i.e.800mm centre to centre), representing approximately 0.5 second vibration at the design taxi speed of 10 kt.
- Two groups of ridges were provided for evaluation, spaced at a distance corresponding to between 2 to 5 seconds at the expected taxi speed.
- The design thickness of the ridge profile was designed to be approximately 9mm – 12mm, which was considered technically feasible and did not exceed the maximum height proposed by the *Feasibility of Concept Report*. The shape and build-up of the profile did not present a vertical face greater than 6mm high.
- Ridges extended 6m either side of the taxiway centreline, allowing a passage for emergency vehicles to by-pass the features.
- White coloured material was used to form the ridges. This allowed the yellow taxiway centreline to be reinstated across the feature with a clear contrast to the material of the ridges.

3.3 Communication

Communication with Stakeholders at all stages of the operational evaluation was considered essential to identify and mitigate risks, ensure compatibility of the operational evaluation with the operation of the host airport, and ensure that the effects of the rumble features were fully assessed and recorded.

3.3.1 Consultation

Initial consultation was carried out by meetings with key airport stakeholders (Airside Operations and ATC) and then extended to a wider group by a presentation to the FLOPC (local safety committee).

Verbal presentations were supplemented by proposed construction drawings for the rumble features, and by a full-scale mock-up of the cross-section of a typical ridge.

3.3.2 Briefing

Briefing materials were produced to inform pilots and airside drivers of the developing plans for the operational evaluation. Posters in Briefing Rooms were supplemented by leaflets explaining the reasons for the project and the nature of the evaluation. These were updated after the initial trial installation was installed for stakeholders to examine, and again after installation of the 'live' evaluation features to draw attention to the feedback process.

3.3.3 Feedback

Printed cards to collect factual data about aircraft movements and pilots' feedback about the perception of the rumble features were prepared prior to the installation and circulated to crews via airlines.

In addition to the printed cards, a facility for pilots to return feedback electronically was provided. A document was made available for completion electronically and return via email. This was intended to facilitate feedback from non-based pilots (including visiting GA aircrew).

Similar cards were prepared to collect feedback from airside drivers, and circulated via Airside Operations.

In addition to the formal feedback collection, the project team maintained contact with Airside Operations throughout the evaluation period in order to collect any informal comments that might be made by any airport users to Operations personnel.

It was agreed before the evaluation that a formal feedback system would not be appropriate for ATC since it might adversely affect the controllers' workload. Instead, informal comment from controllers would be collected from time to time to assess the controllers' observations of any effects of the rumble features on air traffic movements. .

3.4 Implementation

A specialist contractor, experienced in working in an airport environment and in application of the marking material specified to form the features, was employed for the physical implementation of the rumble feature. The site works were overseen at each stage, and quality checked, by TPS (the designer) and SIAL Airside Operations.

Implementation was carried out in several stages to mitigate risks and support the initial briefing and consultation process. Details of the works are included at Annex 2.

3.4.1 Pre-Trial

An experimental installation was carried out off-airport to validate the methodology for building up the thermoplastic strips to form a typical rumble feature. This also served as an opportunity to examine possible variations in the dimensions of the strips. Two of the strip profiles trialled were considered feasible: 300mm wide (designated Type A), based on the original concept study, and 200mm wide (Type B), representing a closer approximation of the section of a typical AGL fitting.

3.4.2 Trial

A trial feature was installed on a section of non-operational pavement adjacent to the taxiway at the A1 Hold site, during a night works possession on 1 June 2009. This served to validate the construction methodology on a pavement surface similar to the final location, and provided an example of both the Type A and Type B profiles for briefing and consulting airport stakeholders.

After consideration it was decided to adopt the Type A profile for the operational evaluation. This profile had received general acceptance during initial consultations. Although the Type B profile was closer to the shape of a typical taxiway light, it was considered that the steeper rise and fall over the ridge might be onerous for smaller aircraft.

3.4.3 Operational Evaluation

After a short period of monitoring the trial installation for short-term durability, the prototype features for operational evaluation were installed on Taxiway A close to A1 Hold during night works possessions on 22 – 23 June 2009.

3.4.4 Removal

Throughout the evaluation period, a contingency plan was put in place for mobilising the removal of the features at an early date in the event of any perceived safety or operational problem due to the presence of the features.

On completion of the evaluation period, the features were removed from the taxiway surface. This was carried out during a night works possession on 29 September 2009. Following removal, the taxiway surface was inspected to ensure that the pavement surface was thoroughly clean with satisfactory frictional texture.

3.4.5 Operational conditions

The timing of the evaluation period, during late spring and summer, was chosen to eliminate risks associated with the possibility of icing or snow accumulation in cold weather.

Weather conditions during the evaluation period were generally normal for the time of year, although Met Office records for July 2009 indicated that rainfall for the surrounding area was approximately double the average rainfall for the month. No problems with drainage of surface water from the pavements around the rumble features were reported by Airside Operations.

The evaluation period took place during the operation of the summer schedule at Southampton International Airport.

CHAPTER 4 – Feedback and Evaluation

4.1 Feedback from Pilots

Thirty-five feedback reports were received from pilots during the evaluation period. Some responses appear to be a compilation of a number of aircraft movements over the period. The sample was too small for statistical analysis, but comparison of the reports suggested the following key features:

Range of aircraft types: Aircraft types reporting were predominantly a mix of Emb-195 and Dash-8, which are the principal aircraft types used for scheduled services at Southampton during the period studied.

Taxi Speed: Most reports indicate a taxi speed in the 5 – 10 kt range. Several reports commented that the vibration effects might be alleviated by increasing the taxi speed (one comment suggested an optimum speed of 12 kt). However, there was insufficient feedback from the later stages of the evaluation to identify whether taxi speeds were actually increased to mitigate the vibration effects.

Perception of the vibration stimulus: 49% (17 reports) assessed the vibration as 'Excessive'.

Comments on the feedback forms varied. Some comments indicated vibration sufficient to cause alarm to passengers. Subsequent informal discussion noted that the main gear of aircraft, coming out of the bend in the taxiway onto the features, tended to track diagonally across the features so that the vibration in the cabin was accentuated.

Other pilots commented that the vibration was similar to other normal taxiway conditions, including rough blacktop surfaces or trafficking over maintenance works (steel plates).

A number of pilots indicated that visual warnings such as red stop bars would be preferred because they would be clearly understood and unambiguous.

Typical comments included:

> "Not possible to differentiate between feature and taxiway conditions regularly encountered e.g. metal plates, taxiway lights etc."
>
> "Not possible to differentiate between rough tarmac and rumble strip."
>
> "Any use of permanent feature will not work because it will always have to be passed

anyway when cleared. Simply use stop bars everyone knows what they mean."

"Visual indicators are much better."

51% (18 reports) indicated that the vibration was a distraction, and several comments reinforced a perception that the vibration stimulus was a distraction at the stage of the trajectory prior to entering a runway.

A similar number of reports stated that they did not interpret the vibration as an indicator of approaching (or vacating) a runway.

4.2 Feedback from Airside Drivers

Ten feedback reports were received from drivers during a period 23 June – 1 July 2009, during the early stages of the evaluation. The sample was too small for statistical analysis but key features were:

- Vehicle types varied from light 4WD types to large fire tenders.
- Most drivers reported a speed of more than 10 mph across the features.
- Most drivers assessed vibration as 'Light' to 'Medium'.

One driver reported a "slight loss of traction in the rear tyres". Discussions with Airside Ops did not identify any subsequent reports of this type, either in dry conditions or after rain.

4.3 Feedback from ATC

Informal discussion with pilots suggested that on one occasion a visiting pilot queried whether ATC permission was required to cross the feature, but this was not confirmed by ATC otherwise, it was understood that Air Traffic Controllers did not receive any questions about the feature from the airfield users.

Available information suggests that the Rumble Feature did not generally slow down traffic nor negatively affect capacity.

4.4 Feedback from Airside Operations

Specific data on the perception of the features by Operations personnel is included in the airside driver responses above.

SIAL Airside Operations carried out regular inspection of the rumble features during Level 1, 2 and 3 checks on the condition of the airport pavements and infrastructure. No degradation of the ridges forming the features was reported during the evaluation period.

4.5 Comparison to Key Success Factors

The feedback data received to date was insufficient for detailed quantitative analysis. Most responses relate to the first month of the evaluation period. Some important qualitative judgements could be drawn to assess the performance of the prototype rumble features against the agreed KSF (described at 1.2 above).

4.5.1 Recognition

Feedback from pilots confirmed that the tactile stimulus, of the vibration produced by trafficking the rumble features, was generally discernible by the flight crew.

However the degree of recognition varied, depending on the response characteristics of

particular aircraft types and comparison with other taxiway features such as plated maintenance works.

A significant proportion of respondents indicated that they did not understand that the vibration at the rumble feature indicated a location approaching or vacating a runway. This suggests that rumble features (or other novel installations) may not be effective in assisting situational awareness until they become familiar and their function is clearly understood. Several respondents indicated a preference for visual warning (by red stop bar) rather than tactile (vibration).

4.5.2 Repeatability

The feedback indicated that pilots considered strategies to mitigate what many viewed as a distraction. In particular, adjustments to taxi speed were suggested as a means to minimise the level of vibration.

Although there was insufficient recent data to confirm this, it suggested that pilots would over time actively seek to reduce the vibration stimulus in order to mitigate its effects.

4.5.3 Compatibility

As noted in 4.5.1, some pilots commented that the vibration at the rumble feature was not easily differentiated from other vibrations due to varying taxiway surfaces. Comments suggested that some aircraft types were more responsive to general taxiway vibration than others.

A number of reports noted comments by passengers and/or cabin crew about the vibrations across the rumble feature. It was reported that the aircraft track, coming out of the bend in the taxiway, resulted in the main gear crossing the features at a slight oblique angle which accentuated vibration in the cabin rather than at the flight deck. This was more noticeable for longer wheelbases (e.g. Embraer 195).

These observations suggest that the effectiveness of rumble features as an alert in general use would not be uniform across the full range of aircraft using a particular airport.

Although some pilots expressed concern at the possible long-term technical effects of trafficking across rumble features, no particular issues were identified.

4.5.4 Throughput

The feedback did not indicate any general effect on runway or taxiway throughput.

CHAPTER 5 – Conclusions

Based on the feedback of the users of the Rumble Feature, it was concluded that a tactile stimulus in the form of vibration, induced by ridges in the pavement surface, was discernible by pilots and airside drivers.

However, the stimulus was not recognised unambiguously, because of differences in the response of different aircraft types to the rumble features and the comparable vibrations produced by some other taxiway features.

Perhaps because of this ambiguity, the feedback indicated no clear benefit in the assistance of situational awareness. Instead, a significant proportion of responses indicated that the vibration was viewed as a distraction and that pilots were actively considering strategies (such as changes in taxi speed) to reduce the vibration and in effect to 'tune out' the alerting stimulus.

Pilot comments also indicated that visual warnings such as red stop bars would be preferred because they would be clearly understood and unambiguous.

The conclusion has been reached that the Rumble Feature is ineffective as a runway incursion prevention measure because of the expected tendency for users to mitigate and thus avoid the alerting vibration.

There was also a concern that if pilots were to adjust their speed, to minimise the vibration from the rumble feature, this could itself be a distraction from the operation of the aircraft at a key point in the trajectory.

For these reasons, work to develop this idea further will not be continued.

ANNEX 1 – Design

This Annex summarises the development of the proposed design criteria for a prototype Rumble Feature, which was developed in the Feasibility of Concept Report (Reference 1).

Principal features determining the effectiveness of a taxiway rumble feature in providing an alert were identified as:

- The frequency and duration of the vibration, and whether it can be differentiated from other natural vibrations (e.g. due to pavement joints, or taxiway lights).
- The positioning of the alert so that it supplements but does not replace the various visual alerts at the entrance to the runway, i.e. the Runway Holding Position (RHP).
- The amplitude of the vibration, which will depend on the vertical dimension (height/depth) of the elements (ridges/grooves) forming the feature.

In addition, the suitability and durability of different methods of forming rumble features, for practical implementation, were assessed.

A1.1 Frequency and Duration

The frequency and duration of the vibration created by a rumble feature would depend on the speed with which the aircraft or vehicle passes over them. Consultation with stakeholders reported a range of 'expected' taxi speeds depending on circumstances:

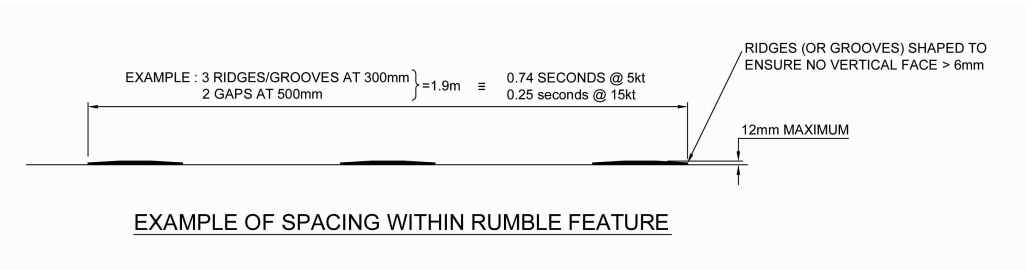
Taxi Movement	Typical Taxi Speed (kt)
Normal taxi - straight taxiway	20 - 45
Runway exit - RET	35
Taxi across runway - expedite	20 - 30
Low-Vis	3 – 10
Assumed at rumble feature	**10**

Knots	Km/hr	Approximate Distance (Metres) travelled in 1 second
3	5.6	1.54
5	9.3	2.57
10	**18.5**	**5.14**
20	37.0	10.29
30	55.6	15.43
40	74.1	20.58

The Taxi speeds in the immediate approach to a runway holding position, where a rumble feature might be provided as a supplementary alert, are expected to be lower than the maximum speeds likely on a straight length of taxiway. For design purposes it was assumed that taxi speeds across a rumble feature would be in the order of **10 knots** (approximately 5 metres/second).

Initial layouts considered a feature consisting of a series of discrete 'bumps', spaced at 1 second intervals, rather than bands of vibration. However, based on 10 kt taxi speed this would result in a spacing of approximately 5m which could be mistaken for centreline lights (installed at nominal spacing of 7.5m in the lead-in/out of junctions on airports licensed for low-visibility operations, a circumstance likely to correspond to the taxiway geometry at many RHP. Ridges/grooves at 5m centres could also be mistaken for the joints in concrete pavements, typically constructed in the order of 4m to 7.5m apart. It was therefore proposed that the ridges/grooves be grouped together at closer spacing.

A rumble feature vibration would need to consist of more than one or two 'bumps' to differentiate it from local irregularities. It was proposed that either 3 or 4 regularly spaced 'bumps' should provide a recognisable signature.



EXAMPLE OF SPACING WITHIN RUMBLE FEATURE

The 'footprint' of a typical Code C – Code E nosewheel (calculated from typical strut loads and tyre pressures) is estimated to be equivalent to a circular area in the range 200mm - 450mm diameter. The width of the ridges or grooves and the spacing between them need to be of the same order of magnitude to ensure differentiation between them as the tyre rolls over.

The following guiding criteria and configuration are proposed as a basis for operational evaluation and further study:

The feature should consist of at least 3-4 transverse ridges/grooves, each 250mm-300mm wide and spaced 300mm-500mm apart, to induce a perceptible vibration for about ½ - 1 second at the assumed taxi speed.

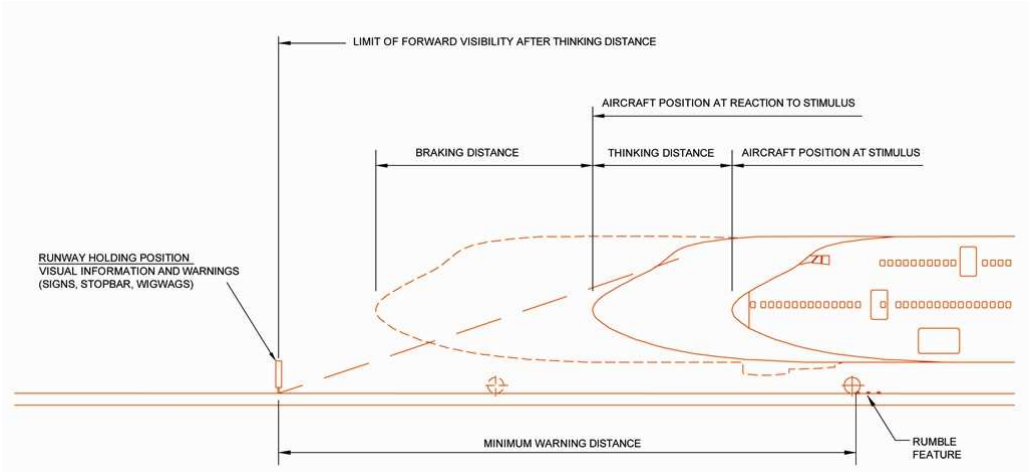
- **Proposed:** *a feature consisting of 4 x 300mm ridges/grooves with 500mm gaps, giving an overall length of 2.7m or 0.5 seconds at 10 kt taxi speed.*

If necessary the alerting effect might be reinforced by providing two or more such groups, spaced approximately 2-5 seconds apart at the expected 'typical' taxi speed.

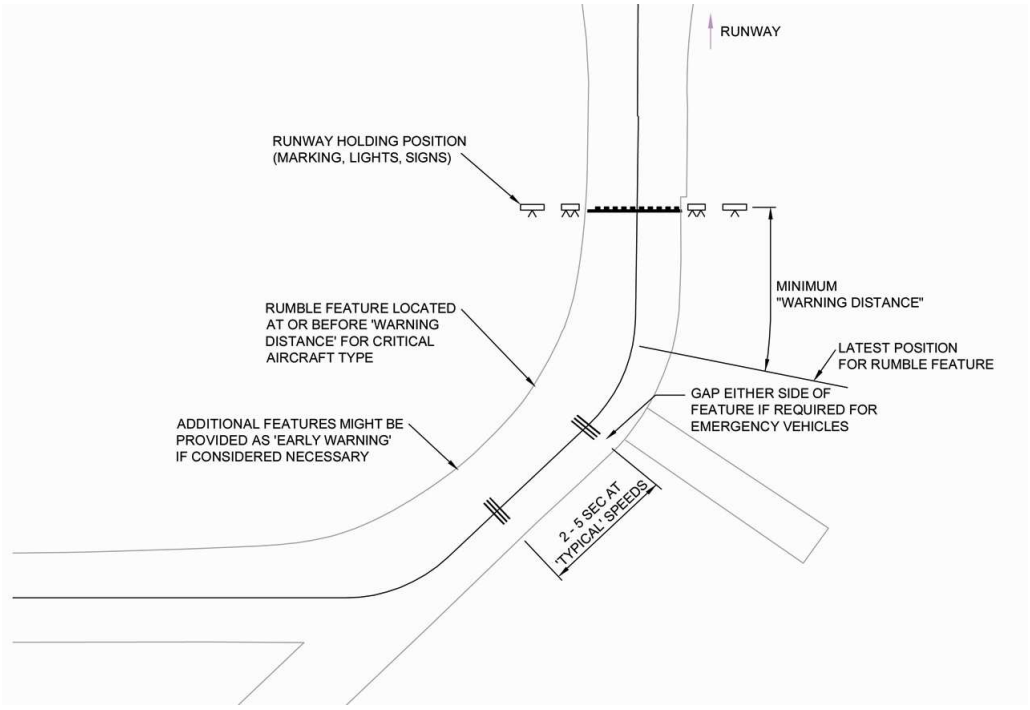
- **Proposed:** *Successive rumble features, if provided, should be spaced 10m – 25m apart to achieve 2-5 seconds separation at 10 kt.*

A1.2 Position

The visual alerts denoting the RHP are located at ground level at the RHP (stopbar lights, taxiway markings) or close to it (signs, wigwags). The position of the pilots' eye relative to these features on the ground may impose a significant constraint on their visibility as the aircraft approaches the RHP: The distance required to prevent a runway incursion must also allow for safe braking of the aircraft; a deceleration of 1/10 g was assumed in developing the concept.



The rumble feature needs to be located a sufficient distance before the RHP to allow reaction/recognition before the aircraft or vehicle would cross the active runway holding point, initiating a runway incursion if there is no valid ATC clearance.



These distances depend on the aircraft type(s) operating at the particular airport:

Aircraft	Nose to Nosewheel	Thinking Distance	Braking Distance (1/10 g)	Distance to Stop	Nose to Pilots Eye	Forward Visibility	Warning Distance
Dash 8 Series 300	2.90	3.45	13.49	19.84	1.07	7.57	12.09
Canadair Regional Jet	2.72	3.45	13.49	19.66	0.59	9.34	13.38
MD-80	2.34	3.45	13.49	19.28	-0.56	11.03	13.92
Embraer 145	2.20	3.45	13.49	19.14	3.53	10.43	17.41
B737	4.09	3.45	13.49	21.03	1.60	13.95	19.00
B767	4.55	3.45	13.49	21.49	2.29	14.40	20.14
B757	5.90	3.45	13.49	22.84	3.66	13.06	20.17
Embraer 195	4.00	3.45	13.49	20.94	2.92	14.58	20.95
A319/A320/A321	5.07	3.45	13.49	22.01	2.66	14.95	21.06
B787-8	5.41	3.45	13.49	22.35	2.64	15.10	21.19
B777	5.89	3.45	13.49	22.83	3.63	14.80	21.88
A330/A340	6.67	3.45	13.49	23.61	4.27	16.15	23.87
A380-800	4.97	3.45	13.49	21.91	2.05	20.28	25.78
MD11	8.50	3.45	13.49	25.44	6.40	17.40	27.25
B747-400	7.88	3.45	13.49	24.82	2.34	25.81	31.60
Design Speed (Knots)	*10*						

In practice, significant landmarks located away from the taxiway centreline (e.g. signs and Runway Guard Lights) would remain visible within the Warning Distance illustrated. Certain aircraft types (e.g. single engine prop aircraft) may have restricted forward vision while taxiing and would thus be dependant on recognition of such landmarks.

A1.3 Amplitude

No data has been found to define suitable amplitude for exciting an 'alerting' vibration in an aircraft. Taking account of the requirement that any surface irregularities (i.e. ridges or grooves) introduced to create a rumble feature must not cause damage to aircraft (Annex 14 Vol 1, 3.9.13, Reference 2), dimensional limits were proposed based on the protrusion of existing taxiway light fittings and the maximum irregularity permitted for joints in new concrete pavements*.*

AGL light fittings such as taxiway and runway centreline lights are installed in areas of the airfield pavement where it is not alien for them to be tracked over by the aircraft wheels. These light fittings by their nature protrude above the airfield surface around the location where they are installed. Annex 14 (Reference 2) states:

5.3.1.8 Surface Lights. Light fixtures inset in the surface of runways, stopways, taxiways and aprons shall be so designed and fitted as to withstand being run over by the wheels of an aircraft without damage to either the aircraft or the lights themselves.

Annex 14 does not specify particular dimensions for light fittings, but in practice the projection of typical taxiway light fittings in current use is in the order of 10mm – 13mm.

- *Maximum vertical dimension:* **13mm** for the height/depth of ridge/groove forming a rumble feature.

Taxiway light fittings are generally slightly tapered in section, so do not present an abrupt step to the aircraft wheel. Similarly, it would be prudent to limit the vertical step presented by a rumble feature. A **maximum vertical face of 6mm** was proposed, corresponding to the maximum irregularity permitted for joints in new concrete pavements.

- *Maximum vertical face (step)* of **6mm**.

A1.4 Implementation

Possible methods or materials for the formation of taxiway rumble features were reviewed to consider:

- Practicality of application, including compatibility with principal materials used to form airfield pavements: pavement quality concrete, or blacktop (bituminous concrete or asphalt) surfacing.
- Durability, and other Operation & Maintenance implications.
- Visibility and how to facilitate recognition by pilots or drivers.
- Potential effects on surface water drainage.
- Practicality of feature removal and reinstatement of a normal pavement surface.

Several possible methods (e.g. systems using elements inlaid on the surface, or fixed to the surface by adhesive) were discounted for use in an aviation environment, typically because of a perceived risk of introducing potential FOD hazards.

Some methods were expected to be sufficiently durable to perform satisfactorily under traffic over a period of years, but would be difficult to remove if used for a short-term evaluation exercise. One method which might be more suitable for short-term use was identified, as summarised below:

	Long-Term Use	*Temporary Use*
New Taxiway Construction	Formed Grooves	*N/A*
Retro-fit to Existing Taxiways	Milled Grooves [$] Proprietary Surfacing Materials [#]	Marking Materials [@]
$ Probable negative effect on pavement strength. # Further research needed. @ Limited life – possible degradation over a period of time.		

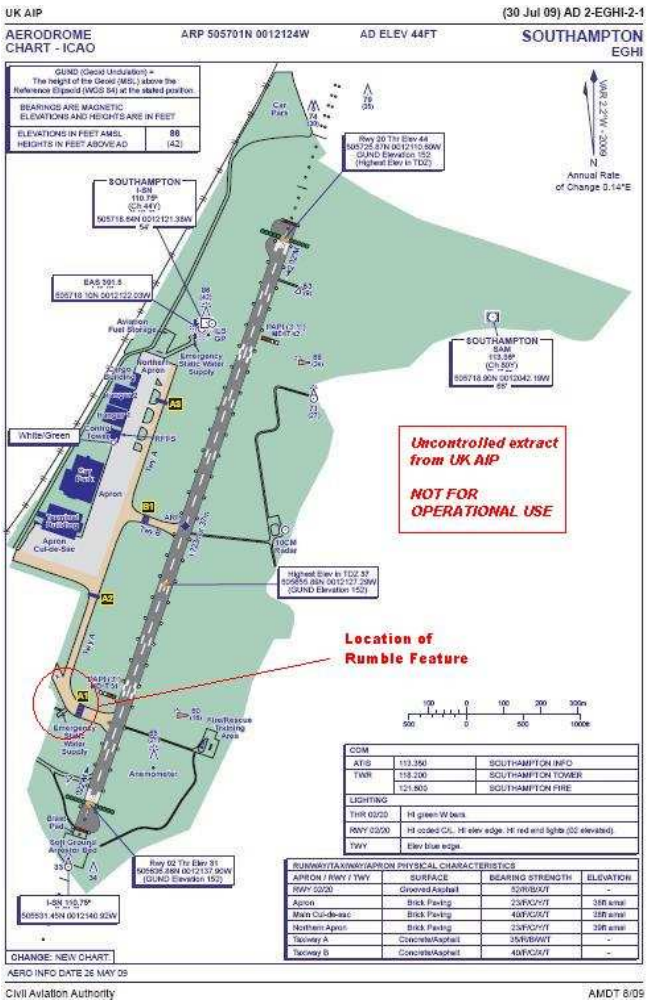
The most likely methods for further consideration for the formation of permanent rumble features, if the concept was proved and accepted, would be permanent grooves either formed in the surface of new pavements during construction, or cut into the surface of existing pavements or newly constructed pavements.

Of the methods identified, the most practicable for a temporary installation would be to create a rumble feature by building-up ridges on the pavement surface using a conventional thermoplastic marking material. This was the methodology adopted for Operational Evaluation.

ANNEX 2 – Prototype Rumble Features

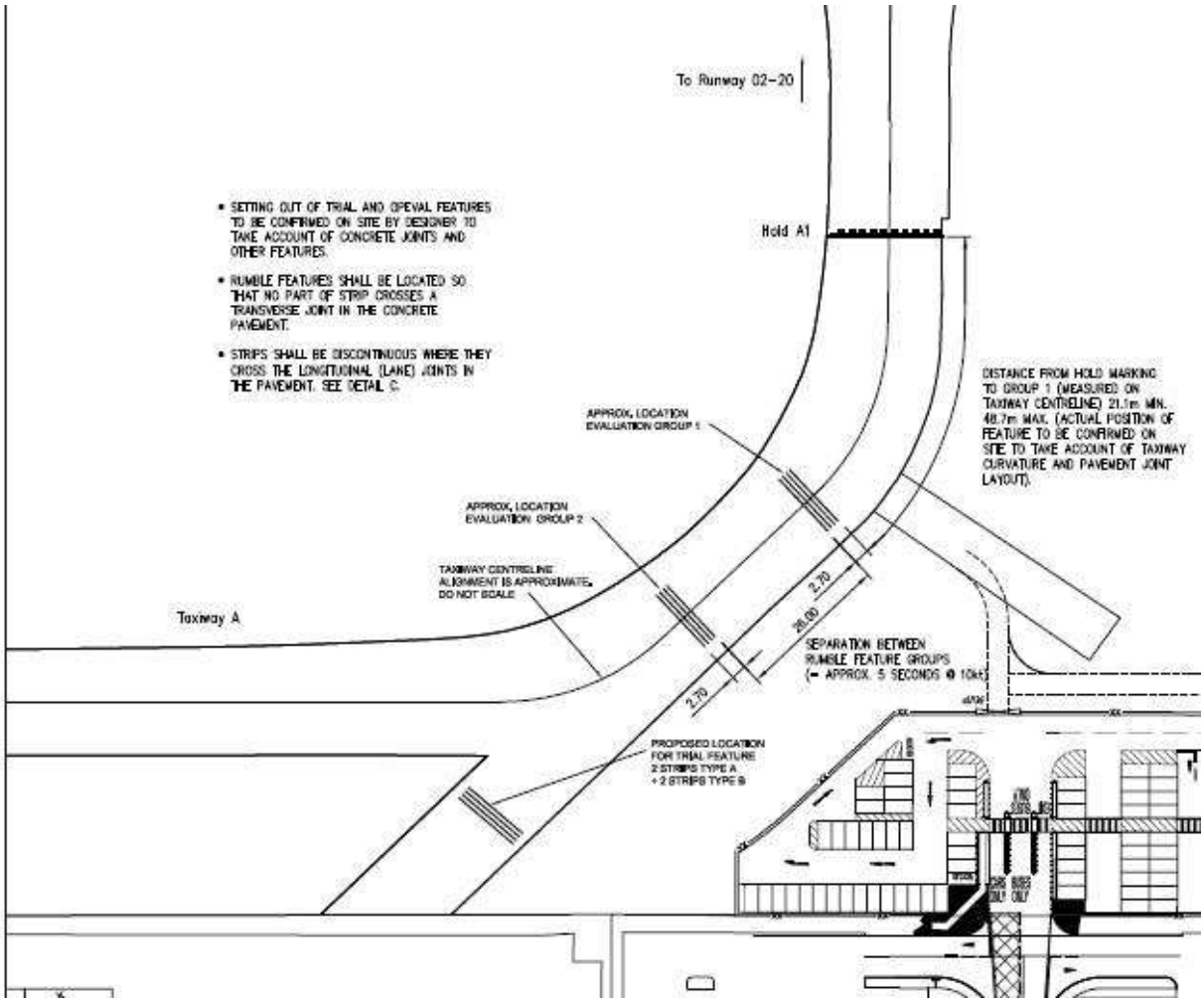
Southampton
International Airport

Plan
indicating location for
operational evaluation of
taxiway rumble features



The prototype rumble features were designed to provide two pulses of vibration, each approximately 0.5 seconds long and spaced 5 seconds apart, at the assumed design taxi speed of 10 knots.

The features were installed on a straight section of taxiway close to the Runway Holding Position. The location was selected with the intention of minimising the effects of aircraft turning at the taxiway bends either side of the straight. In practice, feedback from airport users indicated that the tracking of certain aircraft types (particularly those with longer wheelbase) meant that the main gear crossed the features at a slightly oblique angle accentuating the vibration induced in the main gear.



Prototype Rumble Features

Layout of Features for Trial and

Operational Evaluation

Plate 1

Mock-up of rumble feature strip used for early consultation and briefing

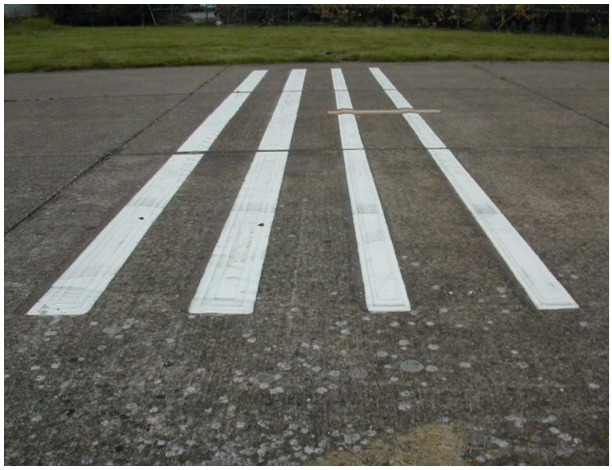


Plate 2

Trial area on disused taxiway spur for consultation with airport stakeholders before operational installation

Plate 3

Detail of Operational Evaluation rumble feature

Plate 4

Rumble features in place during Operational Evaluation

ANNEX 3 – Airport Stakeholders

The following stakeholders (and individual stakeholder representatives) were identified at Southampton International Airport and invited to provide feedback of their experience of using the Rumble Feature.

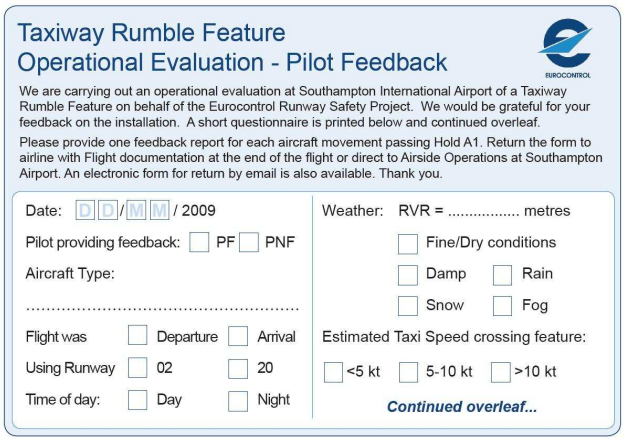
- Aerodrome Operator
    - Local Runway Safety Team (FLOPC) chairperson
- Regulators
- Airlines and Aircraft Operators
    - Safety Managers
- Aircraft Manufacturers
    - Safety Managers
- Pilots:
    - Based airlines
    - Non-based airlines
    - General Aviation
- Air Navigation Service Provider
    - Safety Manager
- Air Traffic Controllers
- Manoeuvring Area Vehicle Drivers (incl. Emergency Services)
    - Fire Service
    - Police
    - Airside Operations (incl. Bird Control)
- Ground Handling Operators

ANNEX 4 – Evaluation of Responses

A4.1 Feedback Proforma

Printed cards were distributed to facilitate feedback from pilots. The cards were designed to collect:

- Factual data on operational conditions of the particular flight (e.g. aircraft type, arrival/departure, visibility, weather, taxi speed).
- Perception of the Rumble Feature, including comments.



Taxiway Rumble Feature
Operational Evaluation - Pilot Feedback

We are carrying out an operational evaluation at Southampton International Airport of a Taxiway Rumble Feature on behalf of the Eurocontrol Runway Safety Project. We would be grateful for your feedback on the installation. A short questionnaire is printed below and continued overleaf.

Please provide one feedback report for each aircraft movement passing Hold A1. Return the form to airline with Flight documentation at the end of the flight or direct to Airside Operations at Southampton Airport. An electronic form for return by email is also available. Thank you.

Date: D D / M M / 2009

Pilot providing feedback: ☐ PF ☐ PNF

Aircraft Type:

.....

Flight was ☐ Departure ☐ Arrival

Using Runway ☐ 02 ☐ 20

Time of day: ☐ Day ☐ Night

Weather: RVR = ... metres

☐ Fine/Dry conditions

☐ Damp ☐ Rain

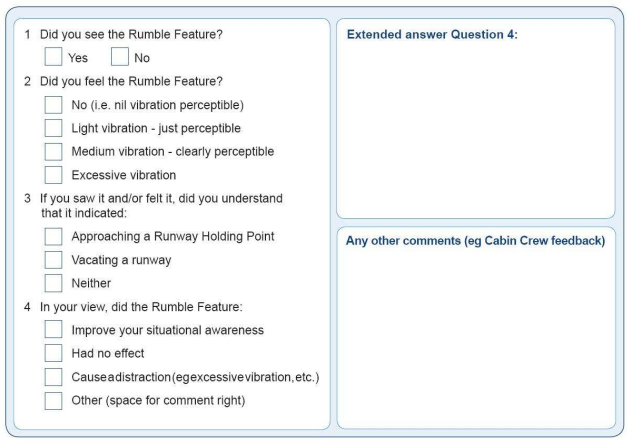
☐ Snow ☐ Fog

Estimated Taxi Speed crossing feature:

☐ <5 kt ☐ 5-10 kt ☐ >10 kt

Continued overleaf...

Pilot feedback – Operational data



1 Did you see the Rumble Feature?
☐ Yes ☐ No

2 Did you feel the Rumble Feature?
☐ No (i.e. nil vibration perceptible)
☐ Light vibration - just perceptible
☐ Medium vibration - clearly perceptible
☐ Excessive vibration

3 If you saw it and/or felt it, did you understand that it indicated:
☐ Approaching a Runway Holding Point
☐ Vacating a runway
☐ Neither

4 In your view, did the Rumble Feature:
☐ Improve your situational awareness
☐ Had no effect
☐ Cause a distraction (eg excessive vibration, etc.)
☐ Other (space for comment right)

Extended answer Question 4:

Any other comments (eg Cabin Crew feedback)

Pilot Feedback – Perception / Comment

Similar cards, with minor modifications, were distributed for feedback from airside drivers.

As an alternative to the printed cards, a proforma in electronic form was made available for download from the Eurocontrol website and return by email.

A total of 35 responses (hardcopy or email) from pilots and 10 responses from airside drivers were returned during the period of the operational evaluation.

A4.2 Operational Conditions

Aircraft types:

The majority of responses were from pilots of Emb-190, Emb-195 or DHC8-Q400 aircraft, corresponding to the principal aircraft types operating scheduled passenger services from SOU.

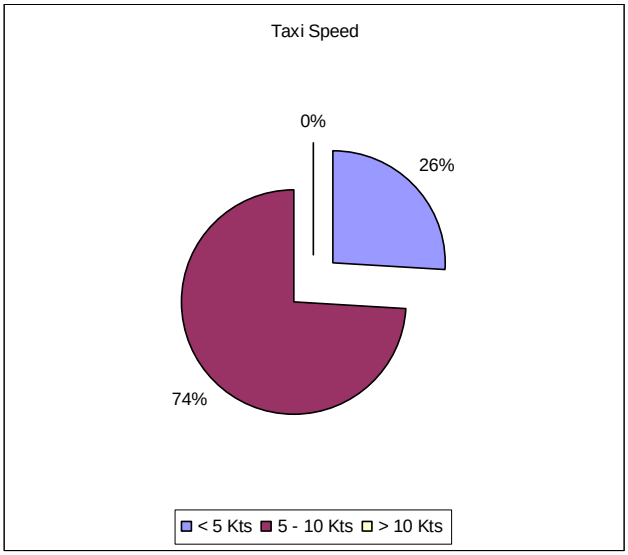
Flights:

The responses covered a range of movements. Over half the responses indicated Runway 20 arrivals, about a quarter 02 Departures, and several of the remainder appeared to be a summary of responses based several flights using either runway direction.

Most were daytime movements, corresponding with the extended daylight hours of the summer period.

Taxi speed:

The majority of respondents reported crossing the rumble features at a taxi speed in the range 5 – 10 knots. None reported a taxi speed greater than 10 knots.



Weather:

Most movements reported fine weather, with a smaller number reporting damp or rainfall. The numbers of responses were too small to make a correlation between the weather conditions and other responses.

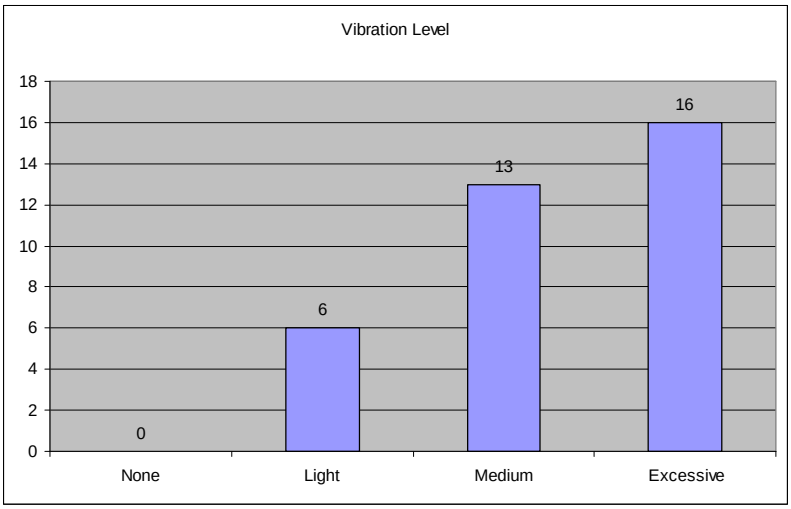
A4.3 Perception

Did you see the Rumble Feature?

All respondents reported that they could see the features on the ground.

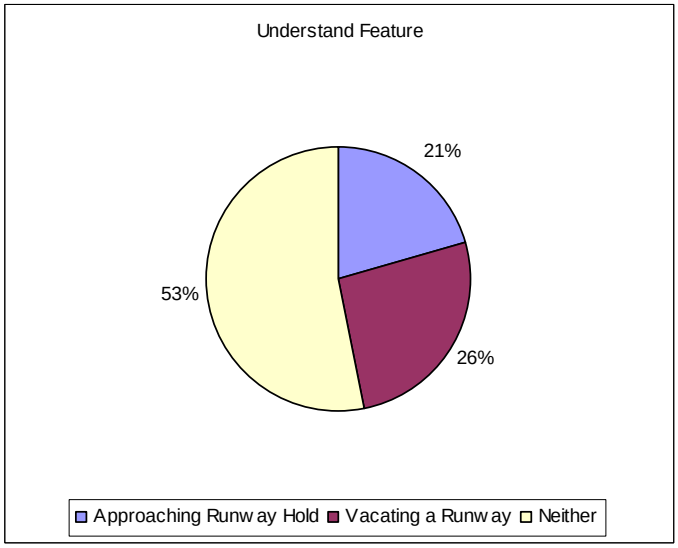
Did you feel the Rumble Feature?

All respondents reported that they could feel the vibration from the rumble features. Perception of the vibration varied as illustrated below.



Understanding of the Rumble Feature:

Over half the respondents did not understand that the presence of the rumble feature was intended to indicate a location at the Runway Holding Position, so that it indicated that the aircraft was approaching a RHP (or, in the opposite direction, that it was in the process of vacating the runway). This may indicate a deficiency in the briefing process or materials prior to the evaluation period.



Effect on Situational Awareness:

Respondents were asked a number of questions intended to assess whether the presence of the rumble feature had, overall, a beneficial or negative effect on situational awareness.

Responses are summarised in the table below:

Effect of the Feature	***Number of Respondents***	***Percentage***
Improve Awareness	0	0%
Cause Distraction	16	50%
None	14	44%
Other	2	6%

A4.4 Additional Comments

Space was provided on the feedback cards to allow respondents to add comments to illustrate or supplement the factual data.

A number of comments were received, illustrating some general strands of opinion in addition to general adverse comments about the effect of additional vibration on rideability.

Similarity to 'normal' taxi-induced vibration: A number of comments indicated that the warning vibration from the rumble feature was not readily distinguishable from other vibrations in normal taxi operations.

- In a Dash 8 there are so many other bumps / vibrations felt on taxi that it is useless
- Not possible to differentiate between feature and taxiway conditions regularly encountered eg. Metal plates, taxiway lights etc. At slow speed, vibration is excessive, counter-productively. The faster you go over them the less effect they have.
- It's similar to taxiing over the metal plates at B1.
- Not possible to differentiate between rough tarmac and rumble strip.
- Due to varying quality of taxiway and apron surfaces and lights on c/l I don't particularly notice a rumble feature.

Preference for visual warnings: A number of pilots commented positively on the effectiveness of visual warnings, in comparison with the adverse comment on the vibration warning.

- Situational awareness for runway incursion is visual eg. Red stop bars / runway board markers with flashing lights.
- No real improvement need a red stop light.
- Visual indicators are much better. Orange wig wag lighting as per most ICAO airports.
- Any use of permanent feature will not work because it will always have to be passed anyway when cleared. Simply use stop bars everyone knows what they mean. You never cross a stop bar, simple.

Potential for distraction: Some pilots identified potential for distraction:

- Nose gear not too bad but as mains cross it felt lke a cattle grid. If a/c not straight then excessive lateral vibration as both mains not in synch.
- This offers nothing but an uncomfortable distraction at a critical time
- Rumble strips distract you at a critical phase i.e. entering a runway.
- We aren't trained to notice vibrations. Its uncomfortable. Potentially encourage people to taxi fast as it is more comfortable. Not a great solution but great that new ideas are being tried.
- The opt. speed for reading the vibrations is 12kts but this speed is too fast for the corner.
- Quite rough! The Dash has a very stiff undercarriage - we can practically feel the taxiway lines, so the rumble lines are quite a shock. In repeated use they are most comfortable if taken fast (faster than normal) which is a little counter productive.

REFERENCES

1. EUROCONTROL. Feasibility of Concept Study – Feasibility of New Airport Infrastructure and Markings (un-published research report). September 2008.
2. ICAO. Annex 14, Volume 1. Aerodrome Design and Operations

GLOSSARY

Key Success Factor	Attribute which must be satisfied in order to achieve mission success.
Rumble feature	Surface texture feature producing vibration as an indication to aircraft and vehicles that they are entering a runway.
Runway Incursion	Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft.

ABBREVIATIONS

ATC	Air Traffic Control
FLOPC	Flight Operations Performance Committee
KSF	Key Success Factor
RHP	Runway Holding Position
SIAL	Southampton International Airport Ltd