



## Accident Report Provides Lessons Learned About Preventing Takeoff on a Closed Runway

*Safety recommendations of the Aviation Safety Council of Taiwan, based on the Singapore Airlines Flight SQ006 accident, discuss the adequacy of some international standards for runway/taxiway signs, marking and lighting. The Boeing 747 struck concrete barriers, runway-construction pits and construction equipment during takeoff in heavy rain, strong winds and low visibility.*

FSF Editorial Staff

On Oct. 31, 2000, at 2317 local time, Singapore Airlines (SIA) Flight SQ006, a Boeing 747-400, struck concrete barriers, runway-construction pits and construction equipment during takeoff on Runway 05R, which was partially closed for maintenance at Chiang Kai-Shek (CKS) International Airport, Taoyuan, Taiwan. Four cabin crewmembers and 79 passengers were killed; four cabin crewmembers and 35 passengers received serious injuries; and one flight crewmember, nine cabin crewmembers and 22 passengers received minor injuries. The airplane was destroyed by collision forces and post-accident fire. Heavy rain and strong winds from a typhoon moving toward Taiwan and runway visual range (RVR) of 800 meters (2,600 feet) prevailed at the time of takeoff on the scheduled flight from CKS Airport to Los Angeles [California, U.S.] International Airport. The declared RVR minimum for Runway 05L/23R was 200 meters (700 feet) at the time of the accident.

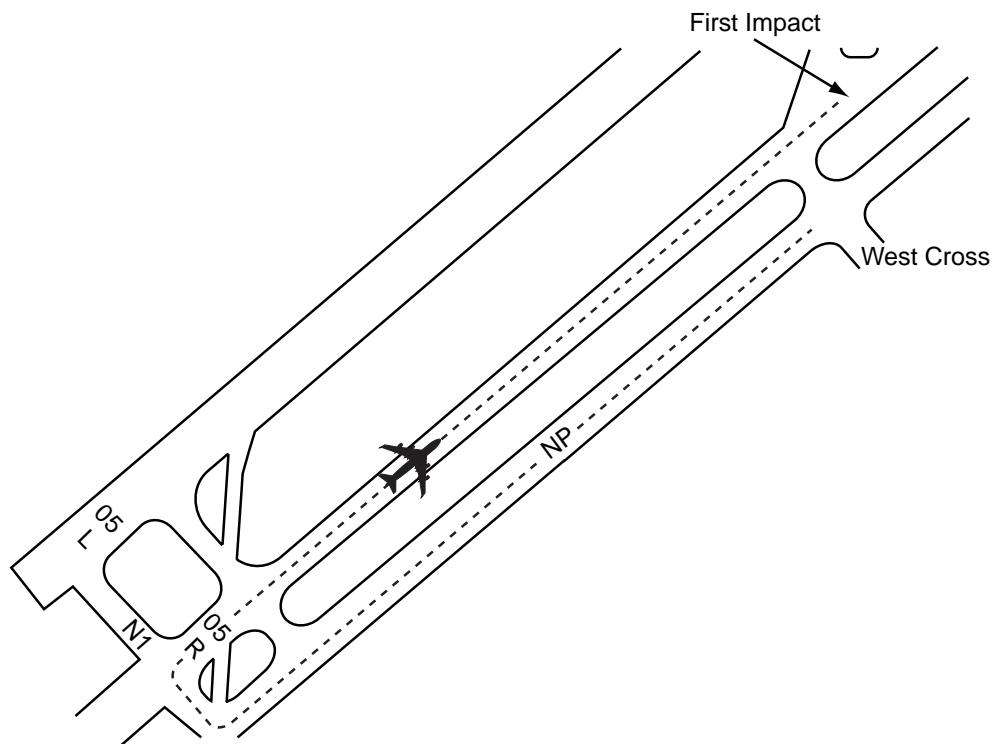
The final report of the Aviation Safety Council of Taiwan (ASC) included the following eight findings related to probable causes (defined as “elements that have been shown to have operated in the accident, or almost certainly operated in the accident ... findings ... associated with unsafe acts, unsafe conditions or safety deficiencies associated with



safety-significant events that played a major role in the circumstances leading to the accident”):

- “At the time of the accident, heavy rain and strong winds from typhoon ‘Xangsane’ prevailed. At 2312:02 Taipei local time, the flight crewmembers of [Flight] SQ006 received [RVR] 450 meters [1,500 feet] from automatic terminal information service (ATIS) [information] ‘Uniform.’ At 2315:22 ... they received wind direction [from] 020 degrees with a magnitude of 28 knots, gusting to 50 knots, together with the takeoff clearance issued by the local controller;
- “On Aug. 31, 2000, [the Civil Aeronautics Administration of Taiwan (CAA)] issued [Notice to Airmen (NOTAM)] A0606 indicating that a portion of Runway 05R between Taxiway N4 and [Taxiway] N5 was closed due to work in progress from Sept. 13, [2000,] to Nov. 22, 2000. The flight crew of [Flight] SQ006 was aware of the fact that a portion of Runway 05R was closed, and that Runway 05R was only available for taxi;
- “The aircraft did not completely pass the Runway 05R threshold marking area and [did not] continue to taxi toward Runway 05L for the scheduled takeoff. Instead,

## Runway 05L and Runway 05R, Chiang Kai-Shek International Airport, Taoyuan, Taiwan



Note: Runway designations and taxiway designations on Oct. 31, 2000.

Source: Aviation Safety Council of Taiwan

**Figure 1**

[the aircraft] entered Runway 05R and [the captain] commenced the takeoff roll (see Figure 1). [The first officer and the relief pilot] did not question [the captain's] decision to take off;

- “The flight crew did not review the taxi route in a manner sufficient to ensure [that] they all understood that the route to Runway 05L included the need for the aircraft to pass Runway 05R before taxiing onto Runway 05L;
- “The flight crew had [Jeppesen] CKS Airport charts available when taxiing from the parking bay to the departure runway; however, when the aircraft was turning from Taxiway NP to Taxiway N1 and continued turning onto Runway 05R, none of the flight crewmembers verified the taxi route. As shown on the Jeppesen ‘20–9’ CKS Airport chart, the taxi route to Runway 05L required that the aircraft make a 90-degree right turn from Taxiway NP and then taxi straight ahead on Taxiway N1, rather than making a continuous 180-degree turn onto Runway 05R. Further, none of the flight crewmembers confirmed orally which runway they had entered;

- “[The captain’s] expectation that he was approaching the departure runway coupled with the saliency of the [green taxiway centerline] lights leading onto Runway 05R resulted in [the captain] allocating most of his attention to these centerline lights. He followed the green taxiway centerline lights and taxied onto Runway 05R;
- “The moderate time pressure to take off before the inbound typhoon closed in around CKS Airport, and the condition of taking off in a strong crosswind, low visibility and slippery runway subtly influenced the flight crew’s decision-making ability and the ability to maintain situational awareness; [and,]
- “On the night of the accident, the information available to the flight crew regarding the orientation of the aircraft on the airport was: [the] CKS Airport navigation chart; aircraft [instrument] heading references; runway and taxiway signs and marking; Taxiway N1 centerline lights leading to Runway 05L; color of the centerline lights (green) on Runway 05R; Runway 05R edge lights most likely not [illuminated]; width difference between Runway 05L and Runway 05R; lighting configuration differences between Runway 05L and Runway 05R;

[aircraft] para-visual display (PVD) showing the aircraft not properly aligned with [the] Runway 05L localizer; and [aircraft] primary flight display (PFD) information. The flight crew lost situational awareness and commenced takeoff from the wrong runway.”

In addition to the preceding finding about time pressure, the analysis section of the report said, “The crew’s concerns about the typhoon and the desire to avoid it may have enticed them to hasten their departure without appropriate attention to details that would correctly identify and confirm the correct runway prior to takeoff. This could have occurred despite the [captain’s] instructions for the crew to take their time and to be careful with checklists and other procedures. ... In the case of [Flight] SQ006, the interview [data] and CVR data indicated that the flight crew sought information that confirmed what they thought; that is, that they were in the correct location [for takeoff]. Confirmation bias [seeking information to confirm an expectation and rejecting information that conflicts with the expectation] may have affected the crew’s decision making in the [accident].”

The report said, “Reduced visibility in darkness and heavy rain diminished, but did not preclude, the flight crew’s ability to see the taxiway [lighting, marking and signs] and runway lighting, marking and [signs]. ATC taxi instructions and the takeoff clearance did not mislead the flight crew to take off from the partially closed Runway 05R. [Flight] SQ006 was cleared for takeoff on Runway 05L and the flight crew confirmed the clearance before takeoff. ... The preponderance of the evidence indicated that the Runway 05R edge lights were most likely not illuminated during the attempted takeoff of [Flight] SQ006.”

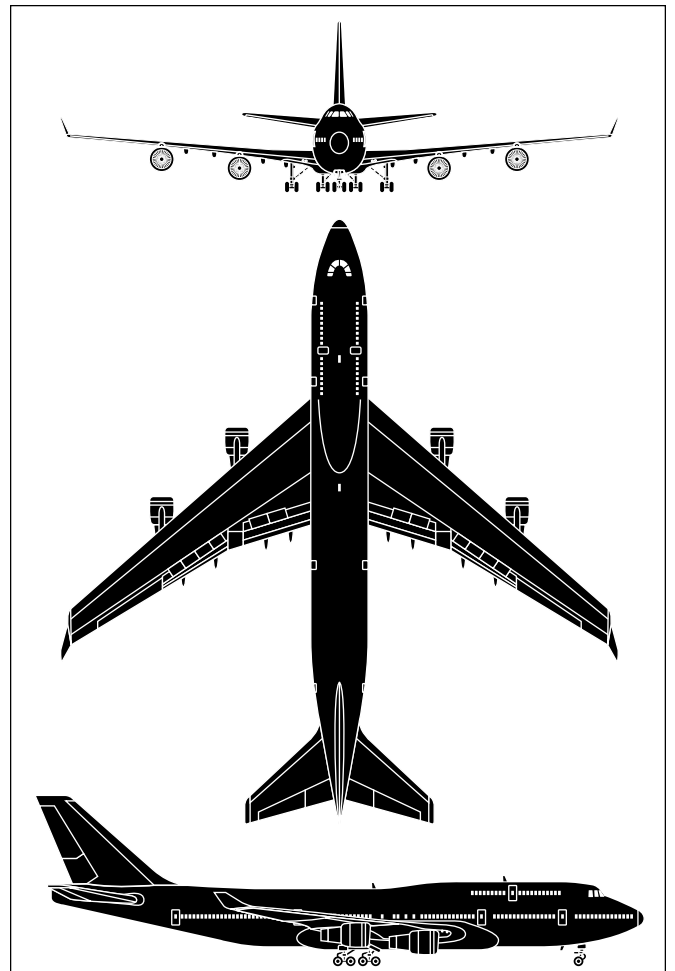
The accident aircraft, a B-747-412B, was delivered to Singapore Airlines in January 1997 and as of Oct. 29, 2000, had 18,459 flight hours and 2,274 cycles. A maintenance “A” check was performed Sept. 16, 2000, when the aircraft had 17,838 flight hours and 2,187 cycles. Investigators’ review of the maintenance records showed no deferred items or open items for the flight, the report said.

The three flight crewmembers had received 23 hours 39 minutes of rest before they reported for duty at 2155 Taipei local time.

The captain had an air transport pilot license (ATPL) and type rating for the B-747-200/300, the Airbus A310-200/300 and the B-747-400. On the day of the accident, he had 11,235 hours, including 2,017 hours in type.

The first officer had an ATPL and type ratings for the A310-200/300, Boeing 777-200/300 and the B-747-400. On the day of the accident, he had 2,442 hours, including 552 hours in type.

The relief pilot had an ATPL and type rating on the A300-200/300 and B-747-400. On the day of the accident, he had 5,508 hours, including 4,518 hours in type.



### Boeing 747-400

An advanced, long-range version of the Boeing 747-300, the B-747-400 entered production in 1989. The airplane has longer wings with winglets, carbon (rather than steel) brakes, more fuel capacity and more fuel-efficient engines than its predecessor. The digital flight deck is configured for two-pilot operation.

The airplane has four engines — either General Electric CF6-80C2s, Pratt & Whitney PW4056 or Rolls-Royce RB211-524Gs. Each engine is rated at 58,000 pounds thrust (258 kilonewtons). Maximum takeoff weight is 870,000 pounds (394,632 kilograms). Maximum landing weight is 630,000 pounds (285,768 kilograms). Maximum level speed at 30,000 feet is 527 knots. Range at long-range cruising speed with 412 passengers and fuel reserves is 7,300 nautical miles (13,520 kilometers).

Source: *Jane's All the World's Aircraft*

Runway 05L/23R was 60 meters (197 feet) wide and 3,660 meters (12,008 feet) long, equipped with an instrument landing system (ILS) and authorized for Category II (CAT II) operations. Runway 05R/23L, for which a scheduled conversion/redesignation as Taxiway NC had been postponed, was still designated as a runway with its remaining portion used for aircraft taxi operations and for takeoff operations at

the time of the accident. Runway 05R/23L was 45 meters (148 feet) wide and 2,752 meters (9,029 feet) long and was designated as a non-instrument runway. Runway 05R was equipped with green taxiway centerline lights for taxi operations, and CKS Airport procedures required the illumination of white runway-edge lights for takeoff operations.

The report said, “[Runway 05R] was not available for landing but pilots were able to request its use for takeoff. Pilots were required to obtain prior approval from both CKS Airport and [air traffic control (ATC)] for the use of the runway [for takeoff]. ... According to the CAA, there was no runway-closed indication in the vicinity of the Runway 05R threshold because this portion of the runway was still being used for taxi [operations] on the night of the accident. In addition, given the inbound typhoon, it was not safe to erect mobile runway-closure signs, which may have been blown into taxiing aircraft. There were warning signs demarcating the construction area on Runway 05R but the distance from the 05R threshold to the construction area precluded the pilots from seeing those lights.”

NOTAM A0606, issued Sept. 13, 2000, said that Runway 05R/23L was closed for takeoff operations because of scheduled construction work on the runway between Taxiway N4 and Taxiway N5. Nevertheless, the approach end and the departure end of the runway, and Taxiway N4 and Taxiway N5 remained available for taxi operations.

CAA officials said that the conversion of Runway 05R/23L to Taxiway NC was postponed because the importation of signs could not be completed by the effective date, the report said. After the Flight SQ006 accident, CAA announced that the conversion, effective Feb. 1, 2001, would include conversion of old runway markings into taxiway markings and disconnection of white runway-edge lights, and the continued use of green taxiway-centerline lights with 30-meter (98-foot) spacing, the report said.

The local controller who issued the takeoff clearance to Flight SQ006, and who was responsible for operating the runway lights, could not see the aircraft line up for takeoff when it began its takeoff roll because of the low visibility, the report said. The distance between the CKS Airport control tower and the threshold of Runway 05L was about 2,000 meters [6,562 feet]. The first time the local controller saw the aircraft was after issuing the takeoff clearance, when he saw sparks followed by an explosion. The ground controller who was responsible for operating the taxiway lights said that immediately before the accident, the white Runway 05L edge lights and white centerline lights were illuminated, the white Runway 05R edge lights were not illuminated and the green Runway 05R centerline lights were illuminated. Another controller said that, in accordance with CKS Airport procedures, the approach lights for Runway 05L were not illuminated for the departure of the accident aircraft.

Each pilot provided to accident investigators reasons for their actions, including which of the exterior visual cues were used, their interpretation of the takeoff “runway picture” and their expectations that signs, marking, lighting and barriers would have reinforced that Runway 05R was closed for takeoff operations.

The captain said that he had conducted flights at CKS Airport on more than 10 occasions using various runways, and that he had conducted about 10 night takeoffs from the airport. He said that he was aware of the NOTAM that applied to work in progress on the northern apron and on Runway 05R.

“[The captain] chose Runway 05L because its Category II category permitted a lower visibility minimum especially when the RVR was declared,” the report said. “In addition, Runway 05L was longer and would afford better performance margins for the prevailing wet runway conditions. ... [The captain] stated that he had experienced worse weather conditions than those that were present at [CKS Airport] on the evening of the accident. ... He had last been in Taipei about two [weeks] to three weeks prior to the date of the accident, but he reported that it had been between two [years] to three years since he had used Runway 05L.”

The captain asked the relief pilot to monitor ATIS broadcasts and to check the wind component. The relief pilot calculated the wind component to be 28.5 knots from the left as the aircraft was taxied toward the end of Taxiway NP and was turned onto Taxiway N1.

“This was still within the company crosswind limit of 30 knots (for a dry runway),” the report said. “[The captain] commented that if the winds had exceeded company operating limits, he would have postponed the takeoff.”

A surface weather observation for 2320 (approximately three minutes after the accident) said that wind was from 020 degrees at 30 knots gusting to 61 knots; visibility was 600 meters; RVR was 550 meters for Runway 05 and 800 meters for Runway 06; heavy rain was reported; broken clouds were at 200 feet and the sky was overcast at 500 feet; the temperature was 21 degrees Celsius (C; 70 degrees Fahrenheit); the dew point was 21 degrees C; the altimeter setting was 1002 hectopascals (29.59 inches of mercury); and wind shear was reported on Runway 05. Based on the cockpit voice recorder (CVR) transcript, the flight crew received the following weather information from ATC before takeoff: at 2307:16, wind from 020 degrees at 25 knots gusting to 41 knots, RVR 450 meters; at 2313:38, wind from 020 degrees at 24 knots gusting to 43 knots; and at 2315:22, wind from 020 degrees at 28 knots gusting to 50 knots.

For visual guidance, the flight crew relied on the taxiway centerline lighting rather than the non-lighted yellow centerline marking, which was difficult to see in darkness and heavy rain.

Moreover, investigators found that the absence of a 20-meter [66-foot] section of yellow taxiway marking, which would have helped the flight crew to see the continuation of Taxiway N1 to the threshold of Runway 05L, probably was not a factor in the flight crew's turn onto the wrong runway.

“On the night of the accident, [the captain's focus] was mainly on the green taxiway-centerline lights,” the report said. “[The captain] stated that these would normally lead him to the takeoff runway. He also commented that he was unable to clearly [see] taxiway [signs] and runway [signs] because of the heavy rain and poor visibility. ... [The captain] turned the aircraft right onto Taxiway N1 and was focused on the image of the runway to his right. He did not notice any further green lights ahead and along the extension of [Taxiway] N1. ... He also commented that there was no continuity of the taxiway line and lights to Runway 05L and [that] ‘this was the trap.’

“During the turn, he had a flash view of the ‘piano keys’ [white runway-threshold marking]. He commented [to investigators] that he was attracted to the bright centerline lights leading onto the runway. As he turned, he did not recall seeing any runway-identification signboard or the runway-identification marking on the runway. ... As the aircraft was lining up, he thought that the image before him was that of a runway. ... When asked to describe his mental picture of a closed Runway 05R, [the captain] replied [that] the closed Runway 05R would not be expected to be lighted up like a runway, would have normal barricades or crosses after the ‘piano keys,’ and runway signs at the beginning of the runway.”

Similarly, the first officer told investigators that a closed runway should be “black” (have no lights illuminated) and should have warning lights. His general perception of a normal runway environment was similar to that of the captain, the report said.

“[The first officer] said [that] the runway picture was ‘correct,’” the report said. “He recalled seeing lights down the middle of the runway and [that] they were very bright. ... He did not see any runway-identification signboard (box), or the runway-identification marking.”

The relief pilot looked up after rechecking the crosswind component and similarly saw a typical runway with bright lights down the centerline. The relief pilot told investigators that the runway lights should not have been illuminated on closed Runway 05R and that there should have been obstruction lights, no-entry signs and barricades.

Although the pilots of Flight SQ006 told investigators that they could see clearly the taxiway-centerline lights and the runway-centerline lights on Runway 05R, they did not recognize that the green centerline lights on the runway where they lined up the aircraft should have been white, the report said.

“[The relief pilot] recalled seeing some information in the NOTAM or [internal notice to airmen (INTAM)] about a green

centerline on Runway 05R,” the report said. “He did not communicate this information to [either] of the other two pilots. He did not know if [either] of the other two pilots were aware of that information. ... The flight crew was aware that the particular runway view should have included white centerline lights and that there should have been an area of bright [touchdown-zone] lights on the runway.”

Based on the transcript of the CVR, at 23:14:41, as the aircraft was being taxied along Taxiway NP, the first officer said, “Next one is November one,” and the captain then said “OK, second right.” The first officer said, “Second right, that's right.”

After receiving ATC clearance to taxi into position and hold, the captain also expected the tower controller to have seen the aircraft before issuing the takeoff clearance, the report said. Shortly after issuing the position-and-hold instruction at 2314:58, the tower controller said, “Singapore Six, Runway zero five left, wind zero two zero at two eight gust to five zero, cleared for takeoff.” The first officer acknowledged the clearance, which coincided with the aircraft approaching the southwestern end of Taxiway NP.

The report said, “At 2315:48, the flight crew completed the before-takeoff checklist. This was followed two seconds later by [the first officer] saying, ‘OK green lights are here.’ [The captain] responded, ‘It [is] going to be very slippery, I am going to slow down a bit, slow turn here.’ According to data from the [flight data recorder (FDR)], the aircraft turned right from Taxiway NP onto Taxiway N1, and made a continuous right turn on Runway 05R.”

During the turn onto the runway, the first officer told the captain that the PVD had not activated. The relief pilot then said that the PVD would arm only within 45 degrees of the runway heading, but after lining up, the PVD remained shuttered. The captain told investigators that “he decided that there was no requirement to use the PVD for centerline guidance during the takeoff because the visibility was sufficient for a visual takeoff.”

The ASC report said that a PVD, according to the Singapore Airlines (SIA) B-747-400 Flight Crew Training Manual, is a device that “allows the pilot to receive directional information from a peripherally located display while maintaining eyes forward and out the window looking for familiar visual cues.” Each of two PVDs on the accident airplane, when tuned to the ILS frequency, was designed to guide the pilot during runway visibility less than 50 meters [164 feet]. When the aircraft is in the correct takeoff position, a shutter opens and the left-streaming movement or right-streaming movement of diagonal black stripes against a white background guides the pilot to steer to correct any divergence from the runway centerline. The PVDs were tuned for use on the accident flight. The report said, “In this [accident], the PVD was still shuttered when the aircraft [was] lined up on Runway 05R. ... The PVD information was an indication that the aircraft was not on the correct runway for takeoff.”

The report said, “At 2316:23, [the captain] stated, ‘not on yet er PVD huh never mind we can see the runway, not so bad. OK, I am going to put it to high first. OK ready er, so zero one zero is from the left lah OK.’ According to the CVR transcript, [the first officer] responded, ‘OK,’ followed by the sound of the windshield wipers going to high speed. At 2316:44, the CVR recorded the sound of engine noise increasing, followed 11 seconds later by both [the first officer] and [the relief pilot] calling ‘eighty knots.’ At 2317:16, [the captain] stated, ‘[Expletive] something there,’ followed one second later by the first sound of impact. Approximately 33 seconds after the takeoff roll commenced, the aircraft collided with several concrete ‘Jersey’ barriers [invented in the 1960s in New Jersey, U.S., for highway uses], two excavators, two vibrating rollers, a bulldozer, an air compressor cart and a pile of metal reinforcement bars on Runway 05R, between Taxiways N4 and N5. The FDR recorded airspeed about 158 knots and ground speed about 131 knots at the end of the recording. At 2317:36, the CKS [Airport] tower controller signaled the emergency bell to the fire station after seeing explosions and fire along the takeoff path of the aircraft.

“According to information provided by the CKS Airport, due to the high wind conditions and heavy rain associated with typhoons at CKS Airport, the light plastic, frangible markers with red obstruction-light markers may be either washed away or blown away, therefore posing a risk of foreign object damage (FOD) to aircraft. To prevent such occurrences, CKS Airport used concrete Jersey barriers, about 0.8 meters [2.6 feet] high, and one meter [3.3 feet] long, placed in close proximity to construction zones. The blocks were painted yellow, orange or a combination of yellow and black stripes. Battery-powered, flashing red warning lights spaced at a distance of two [meters, 6.6 feet] to five meters [16 feet] were installed on top of the blocks for nighttime use. At the time of the accident, these Jersey barriers were the only visual aids on the runway to identify the construction zone. Both approach ends of [Runway] 05R and [Runway] 23L remained open and unobstructed because they were being used as taxiways.”

ATC initially told aircraft rescue and fire fighting (ARFF) personnel that the crash site was on the runway in use (Runway 05L/23R), but ARFF vehicles were driven to the location where the flames were seen.

“[The driver of the first ARFF vehicle to reach the site] encountered low visibility, strong winds and heavy rain ... [and was] guided by the green centerline taxi lights along Taxiway East Cross and the visual sighting of the fire at the crash site,” the report said. “According to the interview with the [airport] fire chief, the forward and mid sections of [the aircraft] burst into flames after the impact. As the fire fighters rushed to the site, they found the aircraft nose section, mid section and wings all on fire. The fire was intense under the gusty winds.”

After 10 minutes to 15 minutes, the fire was under control but flashback — propagation of a flame from an ignition source

back to a supply of flammable gas or liquid — and reignition occurred. Firefighters fully extinguished the fire after 40 minutes, and they found only minor exterior fire damage to the severed rear section, the report said.

The aircraft occupant fatality rate was 46 percent; the serious injury rate was 22 percent; the minor injury rate was 18 percent; and 14 percent of occupants were not injured. The main deck mid cabin, from row 31 to row 48, was not a survivable area because of the fuel-fed fire, and 64 of 76 passengers died in this area. A total of seven autopsies showed that severe burns were the cause of death for six people and impact injuries were the cause of death for one person.

“All passengers in the tail section [where there was less fire] survived,” the report said. “No slides were fully functional for survivors’ evacuation in this accident because of impact forces, fire and strong wind.”

The report contained 36 findings related to risk (defined as “elements of risk that have the potential to degrade aviation safety ... findings ... [that] identify unsafe acts, unsafe conditions and safety deficiencies, including organizational and systemic risks, that made this accident more likely; however, they cannot be clearly shown to have operated in the accident alone”) and 28 other findings (defined as “elements that have the potential to enhance aviation safety, resolve an issue of controversy or clarify an issue of unresolved ambiguity”).

Among the ASC report’s findings related to risk were the following issues relevant to closure of a runway:

- “Based on the current [International Civil Aviation Organization (ICAO)] Annex 14 [*Aerodromes*, Volume 1] standards and recommended practices (SARPs), the CKS Airport should have placed runway-closure markings adjacent to the construction area on Runway 05R; however, there was no [ICAO] requirement to place runway-closure markings near the threshold of Runway 05R;
- “There is ambiguity in ICAO Annex 14 SARPs regarding a temporarily closed runway because the term ‘short term’ is not defined;
- “ICAO Annex 14 SARPs, regarding a temporarily closed runway that is still used as a taxiway, do not provide adequate information with respect to warning flight crews that the runway is closed for other than taxi operations;
- “Although there are no clear ICAO regulations for placement of warnings on temporarily closed runways that are also used for taxi operations, the lack of adequate warnings at the entrance to Runway 05R did not provide a potential last defense, from an airport infrastructure

perspective, to prevent the flight crew of [Flight] SQ006 from mistakenly entering Runway 05R; [and,]

- “Based on ICAO SARPs, the barriers placed around the construction area on Runway 05R should have been frangible.”

The findings related to risk said that a number of items of CKS Airport infrastructure did not conform to internationally accepted standards and recommended practices, but they were not considered sufficient to have caused the loss of situational awareness by the flight crew. Among these items were:

- An unserviceable green taxiway centerline light followed by a dim taxiway-centerline light, located immediately after the Runway 05R entry point along Taxiway N1 leading to Runway 05L, although investigators could not determine with certainty the status of the two lights before the investigators’ inspection;
- A more conspicuous appearance of curving green centerline lights leading from Taxiway NP onto Runway 05R compared to the straight segment of Taxiway N1 centerline lights because the curving lights were spaced more densely. The report said, “There should have been 16 centerline lights spaced 7.5 meters [25 feet] apart along the straight segment of Taxiway N1 where the curved taxiway centerline marking from Taxiway NP meets Taxiway N1 up to the Runway 05L holding position, rather than four centerline lights spaced at 30 meters [98 feet], 55 meters [180 feet], 116 meters [381 feet] and 138 meters [453 feet];”
- The yellow taxiway centerline marking on Taxiway N1 did not extend to the Runway 05L threshold marking and was not interrupted from 12 meters [39 feet] before the Runway 05R threshold marking to 12 meters after the Runway 05R threshold marking. The report said, “The single-line taxiway centerline marking on [Taxiway] N1 extended in a continuous arc from Taxiway NP to the approximate centerline entry point of Runway 05R.”
- CKS Airport Runway 05L did not have stop bars<sup>1</sup> or runway guard lights<sup>2</sup> (alternately flashing yellow lights collocated with runway-holding-position marking that identify the presence of an active runway and signify the holding position);
- CKS Airport did not have alternate green/yellow taxiway centerline lights to demarcate the limits of the ILS sensitive area;
- “The mandatory guidance signs installed on the left and right sides of Taxiway N1 were located after the holding position for Runway 05L and not collocated with the runway holding position marking,” the report said;

- CKS Airport did not have an interlock system to prevent the simultaneous operation of the white runway-edge lighting of Runway 05R and the green taxiway centerline lighting when Runway 05R was used for taxi operations;<sup>3</sup> [and,]
- The lighting system at CKS Airport did not enable continuous monitoring of individual lamps, or monitoring of the percentage of unserviceable lamps, for any circuit.

Among the ASC report’s findings related to risk were the following issues relevant to airport systems and safety oversight:

- “Airport Surface Detection Equipment (ASDE) is designed to reduce the risk of airport ground operations in low visibility, but there are no ICAO SARPs requiring the installation of ASDE at airports. The [ASC] was not able to determine whether ASDE would have provided information to the air traffic controllers (ATC) about [the accident aircraft] taxiing onto the incorrect runway, because signal attenuation from heavy precipitation diminishes the effectiveness of the radar presentation. [The Taiwan Ministry of Transportation and Communications approved a CAA plan for procurement of ASDE on Aug. 15, 2001; CAA first requested funding of ASDE in 1994, the report said.];
- “There was a lack of a safety oversight mechanism within CAA that could have provided an independent audit/assessment of CKS Airport to ensure that its facilities met internationally accepted safety standards and practices;
- “There was a lack of a specified safety regulation monitoring organization and mechanism within the CAA that resulted in the absence of a mechanism to highlight conditions at CKS Airport for taxiways [lighting] and runways lighting, marking and signage that did not meet internationally accepted safety standards and practices;
- “The CAA had not formed a working group for the derivation of a complete surface movement guidance-and-control system (SMGCS) plan according to guidance provided by ICAO Annex 14;
- “Being a non-contracting state, the CAA of [Taiwan] does not have the opportunity to participate in ICAO activities in developing its airport safety enhancement programs to correspond with international safety standards and recommended practices; [and,]
- “The local controller did not issue progressive taxi/ground movement instructions and did not use the low-visibility taxi phraseology to inform the flight crew to slow down during taxi [including phraseology in CKS

Airport standard operating procedures that part of the airport was invisible from the tower].”

Among the findings related to risk, the report said that the flight crew did not request progressive taxi instructions from ATC, and that the flight crew was able to see the visual aids for taxiways and runways although darkness and heavy rain reduced visibility. The report said that the captain did not order cabin crewmembers and passengers to initiate the emergency evacuation when he determined that the public address system was inoperative. During evacuation in dark conditions, only the first officer, relief pilot and 5L cabin crewmember carried flashlights, and the 5L cabin crewmember used the flashlight to assist during the passenger evacuation.

Among the report’s findings related to risk were the following issues relevant to procedures and training of the air carrier:

- “The SIA crosswind limitation for a ‘wet’ runway was 30 knots and for a ‘contaminated’ runway was 15 knots. [The captain] assessed that the runway condition was ‘wet’ at the time he prepared for takeoff and determined that the crosswind was within company limitations. The lack of SIA [procedures] and ATC procedures for quantitatively determining a ‘wet’ versus [a] ‘contaminated’ runway creates ambiguity for flight crews when evaluating takeoff crosswind limitations.” (The report said that the SIA operations manual contained a crosswind limitation of 30 knots and did not differentiate between wet and dry runways; the SIA flight crew training manual, as training guidelines only, used crosswind limits of 30 knots for a dry runway, 25 knots for a wet runway and 15 knots for a contaminated runway.);
- “There was no procedure described in the SIA B-747-400 operations manual for low-visibility taxi operations;
- “There was no formal training provided to SIA B-747-400 pilots for low-visibility taxi techniques;
- “SIA did not have a procedure for the pilots to use the PVD as a tool for confirming whether the aircraft is in a position for takeoff in low-visibility conditions such as existed for the operation of [Flight] SQ006 on the night of the accident;
- “SIA procedures and training documentation did not reflect the [Civil Aviation Authority of Singapore (CAAS)]-approved B-747-400 [aircraft flight manual (AFM)] supplement regarding use of the PVD for confirming the correct takeoff position;
- “CAAS oversight of SIA operations and training did not ensure that the approved B-747-400 AFM supplement regarding the use of the PVD for determining whether the aircraft is in a correct position for takeoff was

incorporated into the SIA documentation and operational practices;

- “At the time of the accident, SIA’s aircraft operations manual did not include ‘confirm active runway check’ as a before-takeoff procedure;
- “The SIA training and procedures for low-visibility taxi procedures did not ensure that the flight crew possessed the appropriate level of knowledge and skills to accurately navigate the aircraft on the ground;
- “CAAS had not performed sufficient safety oversight of SIA’s procedures and training, and the deficiencies in SIA procedures and training were not discovered during routine CAAS safety oversight;
- “The SIA typhoon procedure was not well defined and the personnel who were obliged to use the procedure did not fully understand the procedure and their responsibilities; [and,]
- “During the annual recurrent emergency evacuation training, which was integrated with the cabin crew [training], the flight crew played the role of passengers. The SIA procedures did not require the flight crew to give the evacuation command.”

Among the ASC report’s findings related to risk were the following issues about the effects of specific accident circumstances on crewmembers’ ability to conduct emergency procedures:

- “The severe impact forces and rapidly spreading fire and smoke rendered much of the existing emergency evacuation training, hardware and procedures ineffective;
- “A majority of the cabin crewmembers’ performance was affected because of the unexpected dynamics of the accident;
- “The dense smoke made breathing difficult and [made] the emergency lights less visible for the survivors during the evacuation;
- “The high lateral G forces associated with the accident produced an unexpected self-inflation of the 4R and 5R slides in the cabin; [and,]
- “The manufacturer of the emergency evacuation slides did not provide information on the effects of high wind in the operator’s manual.”

Regarding CKS Airport, the report’s findings related to risk said that the airport did not prescribe in detail the emergency medical treatment procedures and the responsibilities of the medical coordinator or the interim medical coordinator, or contingency



procedures for medical treatment and rescue in adverse weather conditions as recommended by ICAO.

“The *CKS Airport Civil Aircraft Accident Handling Procedures and Regulations* contained incomplete features of the surrounding hospitals (such as neurosurgical ability) as suggested in the ICAO recommendations,” the report said.

Another finding was that the fire department was understaffed in handling a major accident, the report said.

Advisory information developed for U.S. programs to prevent runway incursions has been adopted, as appropriate, by civil aviation authorities of other countries. This information should be considered by international airport safety specialists who are involved in improving methods of preventing the misidentification of runways by flight crews, the report said.

For example, investigators found that some taxiway-centerline lights did not meet either current SARP or current U.S. practices. The ACS report cited U.S. Federal Aviation Administration (FAA) AC 150/5340-1H, *Standards for Airport Markings (Change 1) – Article*, which recommends that for taxiways used for low-visibility operations (RVR less than 1,200 feet [360 meters]), taxiway-centerline marking should continue across all runway marking with the exception of the runway-designation marking.

“At exit [taxiways] and entry taxiways, [taxiway] centerline lights also extended into the runway up to the runway centerline area,” the report said. “Taxiway centerline lights were also provided along the centerline of Runway 05R/23L (no runway centerline lights were installed [on Runway 05R/23L]). ... There were no alternate green/yellow taxiway centerline lights on existing taxiways to demarcate the limits of the ILS sensitive area. For an aircraft taxiing along Taxiway NP, the spacing of the green taxiway-centerline lights on the straight portion of Taxiway NP was 30 meters. As [the aircraft] turned right into Taxiway N1, the spacing of taxiway-centerline lights along the curved section was 7.5 meters up to the point of tangency with the runway centerline. Beyond that, the spacing of green taxiway centerline lights was 30 meters along Runway 05R/23L. Along Taxiway N1 toward Runway 05L, there were four taxiway centerline lights along the straight segment of Taxiway N1 up to the Runway 05L holding position.”<sup>4</sup>

The ASC report cited one ICAO recommendation and three ICAO standards from Annex 14, Volume 1, relevant to denoting construction areas on temporarily closed runways and to denoting partially closed runways:

- “Recommendation – A closed marking should be displayed on a temporarily closed runway or taxiway or portion thereof, except that such marking may be omitted when the closing is of short duration and adequate warning by air traffic services is provided [paragraph 7.1.2];

- “[Standard –] On a runway, a closed marking shall be placed at each end of the runway, or portion thereof, declared closed, and additional markings shall be so placed that the maximum interval between markings does not exceed 300 meters [984 feet]. On a taxiway, a closed marking shall be placed at least at each end of the taxiway or portion thereof closed [paragraph 7.1.3];
- “[Standard – Note –] When an area is temporarily closed, frangible barriers or markings utilizing materials other than paint, or other suitable means may be used to identify the closed area [paragraph 7.1.4]; [and,]
- “[Standard –] In addition to closed markings, when the runway or taxiway or portion thereof closed is intercepted by a usable runway or taxiway, which is used at night, unserviceability lights shall be placed across the entrance to the closed area at intervals not exceeding three meters [paragraph 7.1.7].”

Design differences and configuration differences between Runway 05L and Runway 05R were significant, the ASC report said. They included the widths, the types of lights, the color of lights and the runway touchdown-zone marking stripes.

Investigation of the accident included the use of a B-747-400 Freighter to study the conspicuity of taxiway signs and markings and runway signs and markings from the flight deck. The captain’s field of view and the first officer’s field of view were modeled based on fixed eye-reference points with vision through the areas swept by the windshield wipers.

The field-of-view study found that the following cues would have been visible from the accident-aircraft flight deck during the two final turns: the Taxiway N1 sign and the Taxiway N1 centerline lights leading to Runway 05L; the Runway 05R sign; the Runway 05R threshold marking and designation; and the Runway 05L signs.

“In particular, the study indicated that the ‘N1/5R–23L’ [signs were] visible from [the captain’s] eye reference point through [the captain’s] windshield when the aircraft was turning from Taxiway NP onto Taxiway N1,” the report said. The study also revealed the following issues relevant to signs, markings and lighting:

- “Runway lights on Runway 05L were difficult to see at intensity level 1 and [level] 2 set by CKS Airport Tower. ... The lights were set at intensity [level] 3 [with level 5 the highest intensity] on the night of the accident;
- “There was no marking to indicate that the runway was closed;
- “Lights on obstructions and obstacles on Runway 05R were not visible from the cockpit;

- “Runway marking ‘05’ and ‘R’ were visible from the flight deck when the aircraft was turning from Taxiway N1 on Runway 05R; and,
- “After the aircraft had lined up, the runway marking ‘05’ and ‘R’ were no longer visible from the flight deck.”

One conclusion of ASC was that the flight crew’s attention became focused on a few environmental cues and that, therefore, other cues about the position of aircraft were missed. The report said that under the prevailing environmental conditions, however, the flight crew of the accident aircraft might not have been able to perceive that the runway was too narrow to be Runway 05L.

At Changi Airport, home base of SIA in Singapore, the taxiway lighting control system detects conflicts in multiple taxi routes and provides an interlocking system of taxiway centerline segments and stop bars to resolve conflicts at taxiway intersections. In operation, Changi Airport ATC illuminates taxiway centerline lights for the assigned taxi routes and then instructs pilots to “follow the green.” CKS Airport did not have this type of taxiway lighting control system and pilots were required to navigate visually using airport charts, aircraft instruments and visual aids on taxiways and runways.

ASC investigators — citing academic research on situational awareness related to mental models developed from repetitive experiences — said, “During interviews, all three pilots [who had worked for SIA and flown in and out of Changi Airport for at least five years] stated that the green taxiway centerline lights should have taken them to the takeoff runway. During the turn from Taxiway NP through [Taxiway] N1 onto Runway 05R, [the captain] may have reverted to following the green because of: the salience of the [Taxiway] N1 taxiway lights; [and] a possible reversion to a routine action to ‘follow the green’ at a critical point during the taxi where the flight crew’s attention was preoccupied by taking off in a strong crosswind, low visibility and slippery runway conditions.

“The crew essentially lost awareness of their location during the taxi. None of the three pilots had directed [the crew’s] attention to the runway marking and [signs] during the turn. ... Therefore, the crew could have missed the airport-infrastructure information that may have made them aware that they were taxiing onto the incorrect runway. Further, as [the captain] taxied into position for takeoff, the crew accepted that they were on Runway 05L without verifying their position using the aircraft instrument indications, taxiway/runway [signs] or the runway environment. On runway line-up, the flight crew did not cross-reference their outside picture with the information on the CKS Airport chart. ... Finally, the contrary cockpit instrument indications were not resolved by the crew.”

During interviews with accident investigators, the first officer said that he did not notice any displacement of the localizer on the PFD when the aircraft was lined up for takeoff (and there

was no requirement for this to be checked in the SIA operating procedures or Boeing operating procedures for the B-747-400). The relief pilot told investigators that he looked at the PFD and observed that the frequency was correct, the report said.

“During taxi and runway line-up, the flight crew was presented with aircraft heading indications on the magnetic compass and the aircraft’s heading indicators, which were located on the [PFD],” the report said. “Taxiway NP paralleled Runway 05R/23L. The aircraft heading during the taxi along Taxiway NP would have indicated about 230 degrees magnetic. When the aircraft turned from Taxiway NP onto Taxiway N1, the flight crew needed to maintain a heading of about 230 degrees magnetic for about 270 meters to reach Runway 05L. Instead of making a 90-degree turn from [Taxiway] NP onto [Taxiway] N1 as the airport chart indicated, [the captain] turned the aircraft 180 degrees from a heading of about 230 degrees magnetic to a heading of about 050 degrees magnetic, directly onto Runway 05R. ... Although [the first officer] stated that the compass rose can help maintain orientation during taxi, he did not mention the use of the aircraft’s heading indicators and/or the compass to verify visual orientation during the critical phase of the taxi when [the aircraft] turned from Taxiway NP through Taxiway N1 directly onto Runway 05R.”

When a flight crew tunes the frequency of the ILS for the takeoff runway, as required to use the PVD, two other indications on the PFD — a localizer diamond and a rising runway symbol — show that the aircraft is aligned or is not aligned with the runway centerline, the report said. Investigators also attempted to simulate on the navigation display indications of the position of the accident aircraft relative to the takeoff runway. They were not able to determine what range had been set on the navigation display of the accident aircraft during taxi and runway line-up.

Some ASC conclusions and recommendations were relevant to airport operators and to government/industry review of the adequacy of international standards for runway/taxiway signs, marking and lighting to prevent inadvertent takeoff on a closed runway.

“The [ASC] believes that the provisions of ICAO Annex 14, Volume 1, paragraph 7.1.2 are vague, since it mentions that marking ‘... may be omitted when the closing is of short duration and adequate warning by air traffic services is provided,’” the report said. “Annex 14 does not define or explain what is considered ‘short duration.’ Nor does the guidance address a temporarily closed runway that remains open, in part, for taxi operations. Therefore, there were no ICAO SARPs that would have required or recommended the placement of warnings at the entrance to Runway 05R.

“Nevertheless, the [ASC] believes that the circumstances regarding the planning and execution of the construction project on Runway 05R suggest that CKS Airport management should have taken steps, as part of a risk analysis, to reduce

the risk that flight crews might inadvertently attempt to take off on a partially closed runway. ... If runway guard lights or stop bars or densely spaced centerline lighting along Taxiway N1 had been provided, they would have increased the conspicuity of the Runway 05L holding position and would have increased the probability that the crew [of Flight SQ006] would have been alerted to the location of Runway 05L.”

Airports that close a runway and then continue to use the runway as a taxiway must balance operational needs with an assessment of the risk involved in implementing the change. One method of addressing risk is to communicate clearly the status of runway operations.

“The [ASC] acknowledges that permanent runway-closure barriers at the entrance to Runway 05R would have been impractical, since they would have adversely affected taxi operations,” the report said. “[Nevertheless,] temporary measures, such as clear warnings/alerts or markings/indications — along Taxiway N1 and [Taxiway] N2, and on either side of the entrance to Runway 05R — would have provided an important defense against pilots mistakenly entering the wrong runway. The existence of such temporary measures could also have been noted in the ATIS, in the [*Aeronautical Information Publication (AIP)*] and in NOTAMs.”

ASC safety recommendations included improvements of standard operating procedures for pre-takeoff instrument checks and verification of correct runway (such as by mandatory visual reference to signs and markings); flight crew surface-movement training for low-visibility operations; use of ATC progressive-taxi instructions in low-visibility ground operations; crew briefing about the effect of airport surface construction and maintenance on operations; crew resource management; continual formal monitoring/implementation of SARPs and industry best practices; and infrastructure preparations (such as airport databases and terrain databases) to support new surface-movement guidance/navigation technologies and the implementation of ASDE.

Adherence to internationally accepted standards and practices — for current airport infrastructure and planned improvements — is important because infrastructure helps to defend against the consequences of human error and/or system failures. For example, the airport must consider all the influences that marking and lighting of a taxiway centerline will exert on navigation by a flight crew to the correct runway threshold.

“It is apparent that the Taxiway N1 centerline marking of the CKS Airport did not meet the CAA’s own specifications, the ICAO standard and the FAA AC,” the report said. “This inconsistency was never noticed during design verification, work completion certification [or] in day-to-day operations. The [ASC] believes such discrepancy was due to the lack of an airport-facility specialist that would be responsible for safety surveillance of the airport and the lack of safety oversight mechanism by the CAA.”

In 1999, CAA began an effort to revise civil aviation regulations to reflect the most recent ICAO SARPs; nevertheless, isolation from ICAO has had an adverse influence on the nation’s ability to conform to ICAO SARPs, the report said. ♦

[FSF editorial note: This article, except where specifically noted, is based on the Aviation Safety Council (ASC) of Taiwan Aircraft Accident Report no. ASC–AAR–02–04–001, *Crashed on a Partially Closed Runway During Takeoff, Singapore Airlines Flight 006, Boeing 747-400, 9V-SPK, CKS Airport, Taoyuan, Taiwan, October 31, 2000*. The report contains 508 pages, nine tables, 64 figures and appendixes. Comments from the U.S. National Transportation Safety Board, the Australian Transport Safety Bureau, the Singapore Ministry of Transport (MOT) and CAA were published in appendixes to the report. MOT subsequently published a report titled *Analysis of the Accident to Singapore Airlines Flight SQ 006, Boeing 747-412, 9V-SPK, Taipei, Taiwan, on 31 October 2000*. The MOT report — available on the Internet at [www.sq006.gov.sg](http://www.sq006.gov.sg) — contains 118 pages, 30 photos, 11 illustrations and appendixes.]

## Notes

1. The current International Civil Aviation Organization (ICAO) standards and recommended practices (SARPs) involve the use of the surface movement guidance-and-control system (SMGCS), which includes runway guard lights and stop bars. ICAO Annex 14, *Aerodromes*, Volume 1, paragraph 5.3.17, defines stop bars as lights spaced at intervals of three meters (9.8 feet) across the taxiway, showing red in the direction(s) of approach. The Aviation Safety Council of Taiwan (ASC) accident report on Singapore Airlines Flight SQ006 said that there was no airport SMGCS plan for low-visibility operations provided at Chiang Kai-Shek International (CKS) Airport, Taoyuan, Taiwan. The standard in Annex 14, Volume 1, paragraph 5.3.17.1, says, “A stop bar shall be provided at every runway-holding position serving a runway when it is intended that the runway will be used in runway visual range [RVR] conditions less than a value of 350 meters [1,200 feet], except where: a) appropriate aids and procedures are available to assist in preventing inadvertent incursions of aircraft and vehicles onto the runway; or b) operational procedures exist to limit, in [RVR] conditions less than a value of 550 meters [1,800 feet], the number of: 1) aircraft on the maneuvering area to one at a time; and 2) vehicles on the maneuvering area to the essential minimum.” On Jan. 1, 2001, the following stop-bar standard became effective in paragraph 5.3.17.2, “A stop bar shall be provided at every runway-holding position serving a runway when it is intended that the runway will be used in [RVR] conditions of values between 350 meters and 550 meters, except where: a) appropriate aids and procedures are available to assist in preventing inadvertent incursions of aircraft and vehicles onto the runway; or b)

operational procedures exist to limit, in [RVR] conditions less than a value of 550 meters, the number of: 1) aircraft on the maneuvering area to one at a time; and 2) vehicles on the maneuvering area to the minimum.” Moreover, the report said that U.S. Federal Aviation Administration (FAA) standards for stop bars, in Advisory Circular (AC) 150/5340-28, “Low Visibility Taxiway Lighting Systems,” say, “Stop bars are required for operations below 600 feet (183 meters) RVR at illuminated taxiways that provide access to the active runway.”

2. The standard in Annex 14, Volume 1, paragraph 5.3.20.1, says, “Runway guard lights, Configuration A, shall be provided at each taxiway/runway intersection associated with a runway intended for use in: a) [RVR] conditions less than a value of 550 meters where a stop bar is not installed; and b) [RVR] conditions [of] values between 550 meters and 1,200 meters [4,000 feet], and where the traffic density is heavy.” The function of these lights is to confirm the presence of an active runway and to assist in preventing runway incursions.
3. Regarding airport lighting, the ASC report said that the following standard has been provided by Annex 14, Volume 1, “Where a runway forming part of a standard taxi-route is provided with runway lighting and taxiway lighting, the lighting systems shall be interlocked to preclude the possibility of simultaneous operation of both forms of lighting [paragraph 8.2.3]. ... For example, at

CKS Airport the interlock would have controlled the Runway 05R edge lights and the taxiway centerline lights.” The report said that the CKS Airport lighting system, when installed in 1979, conformed to SARPs, but was not equipped with an interlocking device as provided in 1995 revisions to the SARPs. CKS Airport air traffic control (ATC) procedures did not permit the simultaneous operation of the Runway 05R edge lights and the taxiway centerline lights installed on Runway 05R, the report said. ATC controllers coordinated the manual operation of these lights based on the specific type of operation conducted on Runway 05R.

4. Annex 14, Volume 1, paragraph 5.3.15.13, contains the following recommendation, “On a taxiway intended for use in RVR conditions of less than a value of 350 meters, the lights on a curve should not exceed a spacing of 15 meters [49 feet] and on a curve of less than 400 meters [1,312 feet] radius the lights should be spaced at intervals of not greater than 7.5 meters [24.6 feet]. This spacing should extend for 60 meters before and after the curve.” The ASC report cited the FAA standards for implementation of taxiway-centerline lights. The report said, “[FAA recommends] that centerline lights continue across a runway for operations below 365 meters [1,200 feet] RVR where the taxiway is an often-used route. When taxiway-centerline lights go across a runway, the lights are color-coded green/yellow starting from the center of the runway (AC 150/5340-28, paragraph 3f).

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