2. Analysis

2.1 General

The two flight crewmembers of Gulf Air Flight GF-072 were properly certificated and qualified in accordance with applicable civil aviation regulations of the Directorate General of Civil Aviation and Meteorology (DGCAM), Sultanate of Oman, ICAO standards and Gulf Air company requirements. There was no evidence to indicate that the performance of either member of the flight crew was affected by any medical factors.

The aircraft was properly certificated, equipped, and maintained in accordance with applicable regulations of DGCAM, ICAO standards and Gulf Air company procedures. The aircraft was authorised to operate under the provisions of Sultanate of Oman Civil Aviation Regulations (CAR) Part 121. The weight and balance of the aircraft were within the prescribed limits for landing. No evidence indicated that the aircraft experienced pre-impact failures of its structures, flight control systems or engines. The occurrence was a controlled flight into terrain (CFIT) accident (refer to section 2.4.7).

The air traffic control (ATC) personnel, who provided the ATC services to the flight, were properly certificated and qualified. The approach controller was a trainee who was working under the supervision of an acting ATC watch supervisor. The watch supervisor and the aerodrome (tower) controller were qualified full performance level controllers. The ATC radar and communication equipment was found to be functioning normally.

This analysis examines the accident scenario, including weather factors, flight crew performance and decision making, and other relevant factors during the approach, as well as flight crew fatigue issues. The analysis also examines the performance of the ATC system and personnel, Gulf Air's flight crew training programmes, and DGCAM's safety oversight of Gulf Air. Also included in the analysis is a perceptual study of the final flight path that explores the possibility of spatial disorientation of the flight crew.

2.2 Meteorological Factors on the Approach

A review of the meteorological data pertaining during the approach and final phases of the flight indicated that the cloud ceiling and visibility were OK (CAVOK). That is: a visibility of 10 km or more, no clouds below 1500m or the highest minimum sector altitude, and no weather of significance to aviation. Surface wind direction was easterly at a speed of 8 knots. Hence, weather was not a contributory factor in this accident.

The accident occurred about 1 hour and 24 minutes after the sunset, and there was no moon in the sky. Hence, the accident occurred under what is generally referred to in the aviation industry as a 'dark night' condition. An over-water light visibility study (refer to section 1.16.4) noted that there were no lights visible along the horizon over the water, and a few scattered stars were visible in haze. Thus, the visual horizon was unlikely to be distinguishable over the sea.

2.3 Analytical Methodology

A review of the factual information indicates that this accident was primarily attributable to human factors, there being no technical deficiencies found with the aircraft and its systems. Consequently, the following analysis focuses on these human factors issues, both at the personal and the systemic levels. The analysis adopts the philosophy of Annex 13, which is well articulated by Dan Maurino, Co-ordinator of the Flight Safety and Human Factors Study Programme, ICAO.

> *'To achieve progress in air safety investigation, every accident and incident, no matter how minor, must be considered as a failure of the system and not simply as the failure of a person, or people'.*

The term 'human factors' refers to the study of humans as components of complex systems made up of people and technology. These are often called 'socio-technical' systems. The study of human factors is concerned with understanding the performance capabilities and limitations of the individual human operator, as well as the collective role of all the people in the system, which contribute to its output. There are two primary dimensions of human factors, these being the *individual* and the *system*[51].

In this context the following analysis addresses the human factors issues: *at the individual level*, and *at the systemic organisational and management level*.

2.3.1 Individual Human Factors

In considering the role and performance of individuals it must be recognised that people are not autonomous, they are components of a system. Therefore human performance, including human errors and violations, must be considered in the context of the total system of which the person is a part. There is a need to investigate whether such errors or violations were totally or partially the products of systemic factors. Some examples are: training deficiencies, inadequate procedures, faulty documentation, lack of currency, poor equipment design, poor supervision, a company's failure to take action on previous violations, commercial pressures to take short cuts, and so on.

2.3.2 Organisational and Management Aspects

On recommendation of the ICAO Accident Investigation Group (AIG) Divisional Meeting in 1992, a formal requirement to include organisational and management information in the final investigation report has been in Annex 13 since 1994 (paragraph 1.17). It states:

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[51] A system can be defined as a collection of interconnected components, people and technology, which interact to produce a given output, such as 'safe aviation'. It can be made up of many sub systems - such as air traffic control, or maintenance.

'Pertinent information concerning the organisations and management involved in influencing the operation of the aircraft. The organisations include, for example, the operator; the air traffic services, airway, aerodrome and weather service agencies; and the regulatory authority. The information could include, but not be limited to, organisational structure and functions, resources, economic status, management policies and practices, and regulatory framework.'

The organisations which influenced the operation of GF-072 were: the operator, Gulf Air; the regulatory authority, the Directorate General of Civil Aviation and Meteorology (DGCAM) Sultanate of Oman; and the air traffic services provider at Bahrain International Airport.

2.3.3 The Reason Model of Safety Systems

At the 1992 ICAO AIG meeting[52] it was recommended that the Reason Model should be used as a guide to the investigation of organisational and management factors. The Reason Model[53] is described in the ICAO Human Factors Training Manual (1998, Chapter 2). The model and its application is described in more detail in the book *Managing the Risks of the Organisational Accident* (Reason, 1997)[54].

Operational experience, research and accident investigation have shown that human error is inevitable. Error is a normal characteristic of human performance and while error can be reduced through measures such as intensive training, it can never be completely eliminated. Consequently, systems must be designed to *manage* human error. What follows is an integrated systemic analysis based on information drawn from all the specialist groups involved in the investigation. It is conceptually based on the Reason Model of safety systems.

2.4 Accident Sequence: Description of Approach and Flight Crew Actions

The FDR and CVR information showed the following:

2.4.1 The First Approach

At 1922:50, the ATC (Bahrain Approach) had cleared GF-072 to continue descent to 3,500 ft. At 1923:09, the captain called for "Approach checklist". At 1923:16 the first officer asked "Briefing?". The captain replied "Confirmed". However, there was no evidence of any "approach briefing" having been carried out by the

[52] Report of the ICAO Accident Investigation and Prevention (AIG) Meeting 1992, Agenda Item 1.10.

[53] A theory which provides conceptual structure and context to the analysis of organisational factors involved in the management of human errors is the Reason Model of safety systems.

[54] Reason (1991, 1997) argues that, as with many other high hazard low risk systems, modern aircraft are equipped with such a high level of technical and procedural protection that they are largely immune to single failures, either human or mechanical. They are much more likely to fall prey to an 'organisational accident'. In such accidents latent conditions, or deficiencies, in the aviation system, which arise primarily within the organisational and management areas, combine adversely with local 'triggering events', such as poor weather or technical problems, and with the errors or violations of individuals or teams at the 'sharp end', to breach the system's defences and produce a catastrophic failure.

captain on the 30-minute recording of the CVR. In the absence of any other evidence, it cannot be established whether such briefing was carried out prior to that time period. The SOP's, as specified in the A320 FCOM, require an "approach briefing" to be carried out, at the cruising level, before commencing the descent. The potential benefits of "briefing" and the issue of adherence to SOPs are discussed later in section 2.5.

GF-072 was conducting a VOR/DME (non-precision) instrument approach for Runway 12 at Bahrain. The ATC had asked GF-072 at 1923:21 to "Report (when) established (on the) VOR/DME Runway 12 radial 301 (degrees)". GF-072 was established on the VOR (radial 301 degrees) at about seven nautical miles from the Runway 12 threshold at time 1925:37. Some of the significant events on the first approach are described in Table 8.

Table 8: Some of the significant events on the first approach

Distance from runway 12 threshold		Height	CAS	Flaps	
nm	**Time LT**	**AGL ft**	**knots**	**Posn**	**Event**
9.0	1925:15	1873	313	'zero'	The captain stated, "final descent – seven DME".
7.7	1925:37	1715	272		The captain instructed the first officer to "call established"
	1926:08				The ATC clears GF-072 "to land on Runway 12".
5.2	1926:13	1678	224		The first officer acknowledges the clearance "to land".
	1926:17			'one'	
4.3	1926:23	1500	223		Landing gear selected 'down'.
3.7	1926:37				The captain said to the first officer "visual with airfield"; however, the ATC did not possess this information.
3.2	1926:44	1111	215		
	1926:45				The captain disconnects the auto-pilot (AP) and flight
	1926:47				director (FD), and thereafter flies the aircraft manually.
2.9	1926:49	1000			
2.8	1926:51	976	207		
	1927:06 and again at 1927:13				The captain comments twice "We're not going to make it"
	1927:10			'two'	
1.5	1927:13	672	196		
1.0	1927:23				The captain asks the first officer "Tell him (ATC) to do
[missed approach point]					(for) a three six zero(-degree orbit to the) left".
0.9	1927:25	584	177		Commencement of a left turn.
	1927:29				The ATC approves the three six zero (degree orbit) to the left.
	1927:34			'three'	
	1927:51			'full'	

2.4.1.1 The Approach Configurations

With reference to Figure 1 on page 6, the Instrument Approach Chart of Bahrain Runway 12 VOR/DME Procedure, the final approach fix (FAF) is at seven DME (i.e. about 5 nm from the runway threshold). The standard procedure is to establish the aircraft on the approach path (VOR-radial 301 degrees), and configure the aircraft for the approach prior to reaching the FAF. The "approach configurations" constitute: landing gear 'down', flaps to 'full', altitude 'as required at FAF' [in this case 1500 ft (1494 ft AGL)], and speed V_{APP}. ($V_{APP} = V_{LS}$ + 1/3 headwind component

+ 5 knots). In this case the V_{APP} as calculated by the FMGC was: 130 + 1 + 5 = 136 knots.

Although the aircraft was established on VOR-radial of 301 degrees at the FAF, the other parameters were far from the standard: *the speed was 223 knots instead of 136 knots, the flaps position was 'one' instead of 'full', and the altitude was 1662 ft instead of 1500 ft*. Unless the speed was reduced, the captain could not have selected the landing flaps, i.e. to 'full'. One of the reasons for not achieving the required configurations was excessive speed compared to the standard. At this stage of flight, the SOPs define "deviation from standard" to be when the speed varies by +10 or -0 knots, and/or altitude varies by +/-100 ft.

2.4.1.2 Speeds During the Descent and Approach

Although the captain used speed-brakes three times from 1922:49 to 1926:13 (see footnote 5 of section 1.1), he could not achieve the "approach configurations" before reaching the FAF. Had the speed brakes been used continuously, the captain would have been closer to achieving his objective. The aircraft speed of 223 knots at the FAF was 87 knots in excess of the target speed (i.e. V_{APP} = 136 knots). However, rather than initiating a missed approach, the captain decided to continue with the approach. The speed remained excessive throughout this approach.

The reason for the excessive speed may perhaps be attributed to the planning of descent, or the descent clearance not being integrated into the descent profile. e.g.: At 1921:48, the ATC (Dammam control) had approved a descent to 3,500 ft. However, at 1922:44 the captain said to the first officer, "Tell them (Bahrain ATC) we are cleared to 7,000 (ft)". This statement indicates that he was under the impression that they had only been approved for a descent to 7,000 ft. At 1922:50 Bahrain ATC clarified the instruction: "continue descent (to) 3,500 ft".

In addition, as noted in section 1.17.3.1, there was no specific speed restriction below 10,000 ft within the part of airspace (on the descent path of GF-072) under the control of Saudi Arabia or Bahrain. The Gulf Air procedure for descent and approach specified: "A speed limit of 250 knots below 10,000 ft is the default speed in the managed speed descent profile. The flight crew may delete or modify it if necessary…". The flight crew are expected to check if there are any speed restrictions before selecting speeds higher than 250 knots below 10,000 ft. In other words when there are no speed restrictions specified by ATC, the flight crew could select speeds higher than 250 knots below 10,000 ft. This practice is unlike that in many other airspaces of flight information regions (FIR), and a large number of airlines, which apply a specific restriction of "speed less than 250 knots below 10,000 ft". It is noted that, as one of the post-accident initiatives, Gulf Air issued a Fleet Instruction that stated "A speed limit of 250 knots below 10,000 ft amsl (above mean sea level) is to be observed for normal operations." (refer to Appendix D).

The GF-072 Simulation and Flight Tests, described in sections 1.16.2 and 1.16.3, demonstrated that based on the aircraft configuration, speed and altitude at the FAF, a successful landing could have been achieved - especially if the speed-brakes had been continuously deployed. However, to do so would have involved manoeuvring, requiring a steep approach angle and rapid deceleration, which would have produced severe discomfort for the passengers.

2.4.1.3 Stabilising the Approach

The captain said to the first officer at 1926:37, “visual with the airfield”, and at 1926:51, “have to be stabilised by five hundred feet”, which indicated that he transitioned from an “instrument” to a “visual” approach. However, the ATC was not aware of this information. The A320 FCOM describes the requirements of a visual approach (see section 1.17.3.2) as follows: “Perform the approach on a nominal 3-degree glide-slope using visual references. Approach to be stabilised by 500 feet on the correct approach path, in the landing configuration at V_{APP}”. A standard rate of descent on a 3-degree glide-slope is 300 feet per nautical mile. Hence, to be on the correct approach path would mean to position the aircraft at 500 feet at 1.7 nm from runway 12, and in the configuration: *landing gear ‘down’, flaps ‘full’, height 500 ft, speed 136 knots*. The DFDR showed the actual configuration at 1.7 nm from runway as: *landing gear ‘down’, flaps ‘two’, height 722 ft, speed 198 knots*. The captain did not stabilise the approach on the correct approach path at 500 ft “in landing configuration at V_{APP}”, as required by the SOPs.

At 1927:06 the captain stated “we are not going to make it”. He repeated this remark again at 1927:13. These remarks showed that the captain believed that from that point in the approach, a successful landing could not be achieved. The SOPs call for a “Go-Around” action at this stage (see sections 1.17.3.2), and, as the aircraft was on an instrument approach, to initiate a “standard missed approach” as published in the Instrument Approach Procedure VOR/DME Bahrain Runway 12 (see Figure 1). The Go-Around action should have been as stated in section 1.17.3.4. Instead, the captain elected to carry out a three-six-zero (orbit), and at 1927:23 asked the first officer to “tell” the ATC accordingly. This was a non-standard action, contrary to the SOPs. The apparent objective of the orbit manoeuvre was to lose both speed and height, and reposition the aircraft on the correct approach path, thereby avoiding the need to carry out a missed approach procedure.

An “orbit”, not being an SOP on the final approach, if at all was to be used as a means to achieve target speed and height, the manoeuvre should have been performed before arriving at the FAF, and above the minimum sector/safe altitude (MSA). As one of its post-accident initiatives, Gulf Air issued a Fleet Instruction stating “Once an aircraft is established and descending on the final approach to the runway of intended landing, 360 degrees turns and other manoeuvres for descent profile adjustments are not permitted.” (refer to Appendix D).

2.4.2 The 360-degree Orbit and the Second Approach

The left turn commenced at 1927:25. The orbit was hand flown, and was entered about 0.9 nm from the runway at a height of 584 ft AGL at an airspeed of 177 knots.

After commencing the turn, the captain called for flaps ‘three’ at 1927:33, and thereafter flaps ‘full’ at 1927:44. At 1927:51, the first officer confirmed that the flaps were at ‘full’. The aircraft’s flaps remained fully extended and the landing gear ‘down’ throughout the orbit manoeuvre. Flaps ‘full’ is a flap-setting intended only for the final phases of flight: approach and landing. It is generally selected when a landing can be accomplished. Due to the associated drag, flaps ‘full’ is not a setting for manoeuvring. A recommended setting for manoeuvring is flaps ‘three’, especially if the landing gear is ‘down’. The effect of the high drag induced by the setting of flaps ‘full’ is to degrade the manoeuvrability of the aircraft. This typically results in exaggerated control inputs, or over-controlling, by the pilot. In the present case, the setting of flaps ‘full’ was not appropriate for the orbit. It would have had the effect of making the control of the aircraft more difficult. It explains the nature of the excessive side-stick inputs made by the captain during the orbit. A probable explanation of the pattern of control inputs by the captain is that he was attempting to fly the orbit visually. In the absence of external visual reference, he was periodically looking at the PFD, reading his attitude, making a control input to correct any perceived deviations from the target parameters, and looking out again. As explained above, because of the flaps setting being ‘full’, these control inputs were likely to be excessive, i.e. higher that when in other flap configurations. This was confirmed by the FDR read out.

During the approach and landing phases the recommended rate of turn is “rate one”, which is 3 degrees per second. However, the rate of turn during the orbit was about 4 degrees per second. The captain did not maintain constant attitude and bank angle during the orbit, which are basic flying parameters for conducting such manoeuvres, particularly with high drag (flaps and landing gear down). As noted in section 2.2, the external visual horizon was unlikely to be distinguishable over the sea during the orbit. In such conditions, reference to the aircraft’s instruments is essential for the pilot to maintain spatial orientation and situational awareness, rather than rely upon vestibular or proprioceptive cues[55] which can often be misleading. However, in the present case, it seems that the captain was attempting to rely more upon external visual cues, rather than upon the information displayed on the aircraft’s instruments. In the absence of sufficient external visual cues, one may become susceptible to a false perception of the aircraft’s attitude based on misleading vestibular and proprioceptive cues. The likely result, the spatial disorientation, is discussed in section 2.4.4.

During the orbit, the aircraft’s height ranged from 965 ft to 332 ft AGL. In addition, the orbit was flown at bank angles higher than the standard, which is approximately 25 degrees. The FDR recorded the maximum bank angle as 36 degrees, and the aircraft load factor ranging between +0.5G to +1.5G during the orbit. While conducting aircraft manoeuvres, pilots are expected to concentrate on ‘maintaining attitude’ of the aircraft. In this case the evidence indicates that the attitude was not being maintained. As noted in section 1.17.4.1, the SOPs require that PNF (the first officer in this case) will make call-outs in respect of flight parameters. However, despite a number of deviations from standard, particularly in attitude, bank angle and altitude, the CVR showed no evidence of such call-outs, or any other relevant comments from the first officer. This matter will be discussed later in the analysis.

[55] Vestibular sensations refers to sensations associated with sensory receptors located in the organs of the inner ear responsible for the perception of linear and angular acceleration of the head. Proprioceptive sensations refer to sensations associated with sensory receptors located chiefly in muscles, joints and tendons that provide information about body position and orientation.

The aircraft rolled out of the orbit after completing only about 270 degrees, and took up a heading of approximately 210 degrees, this heading being at about 90 degrees to the extended centre-line of runway 12 (i.e. 121 degrees).

The considerable variations in altitude, bank angle, and 'g' force, during the orbit may have affected the accuracy of the flight crew's perception of the number of degrees through which the aircraft had turned. The final flight path study video (refer to section 1.16.6) shows that for much of the orbit there were very few visual cues for references by means of which the horizon and the aircraft's attitude could be assessed. As the lights of the coast came back into view in front of the aircraft at about 1928:40 when the heading was about 210 degrees, external visual reference was regained.

The captain made no comment as to why he had rolled wings level before he had completed the full 360-degree orbit. There are number of hypotheses which might explain this action. It is possible that having regained a visual horizon reference, and perhaps being uncertain as to how much of the orbit had been completed, the captain rolled the aircraft wings level with the primary aim of regaining his situational orientation. He would then decide upon his next course of action. However, the time taken in making this decision was such that the aircraft flew through the extended runway centre-line, thereby losing the opportunity to reposition the aircraft on the correct approach path from which a successful landing could be achieved.

Shortly after the aircraft wings had been levelled at 1928:47, the first officer called "Runway in sight…three hundred". The flight-path and simulator re-constructions show that at this time runway 12 was clearly visible at about 10 o'clock from the first officer's position. After the first officer's call of 'runway in sight', the aircraft continued on the same heading of about 210 degrees until the captain said at 1928:57 "we overshot it". As he said this, he had already initiated a left turn. The aircraft height at that time was 336 ft AGL.

During the analysis, the possibility was considered that when the aircraft rolled out of the orbit on a heading of 210 degrees, the crew might have temporarily mistaken the lights of a causeway (Shaikh Isa bridge) ahead of the aircraft, for the lights of runway 12. However, the flight-path study indicated that it would be very difficult to mistake the lights of the causeway for runway 12 (refer to section 1.16.6). Both flight crewmembers were thoroughly familiar with the appearance of runway 12 at night, and shortly beforehand had partially completed an approach to that runway. The appearance of the lights of runway 12, which included the distinctive strobe lights, bore no resemblance to the appearance of the causeway lights. In addition, the lights of the moving traffic on the causeway were another obvious cue, which would have prevented the causeway being mistaken for the runway.

Whatever may have been the reason, the aircraft was placed in a position at 1928:57, from where the SOP was "to Go-Around and conduct a missed approach procedure".

2.4.3 Go-around

Once the captain realised that he had overshot the extended centreline of runway 12, he commenced a left turn and the pitch progressively increased, reaching ‘13.7 degrees up’ at 1929:04. This was followed by a nose-down side-stick input, leading to a ‘8.8 degrees pitch up’ at 1929:10. At 1929:07, the CVR evidences the captain saying to the first officer “Tell him (ATC) going-around”, showing that the decision to go-around was taken at that stage. The SOP for a go-around is stated in section 1.17.3.4. The DFDR shows that the action on the thrust levers for the go-around was initiated at 1629:10 (at height 544 ft AGL). However, “rotation to 15 degrees of pitch (up)”, as required by the SOP, was not carried out. The successive side stick inputs from the captain led to the pitch increasing from ‘8.8 degrees up’ to ‘9.1 degrees up’ between 1929:10 and 1929:12. Flaps were selected to position ‘three’ at 1929:20 and the landing gear was selected up at 1929:25. With the side-stick input from the captain, the pitch decreased, reaching ‘6.3 degrees up’ at 1929:35. This shallow pitch (compared to the SOP: 15 degree up), associated with TOGA power, caused the aircraft speed to increase rapidly. The go-around should have been followed by a standard missed approach procedure; i.e.: “to maintain runway heading and climb to 2,500 ft”. However, the captain did not perform the standard missed approach procedure, and continued turning.

2.4.3.1 Radar Vectors

At 1929:08 the first officer reported to the ATC “going-around”. The ATC asked “would you like radar vectors for the final (approach) again?”. When the first officer replied that “we’d like radar vectors”, the ATC gave radar vectors for another approach as: “fly heading 300 (degrees) and climb (to) 2,500 feet” (at time 1929:25). The first office acknowledged the radar vectors to the ATC and then confirmed them to the captain. At 1929:38 the first officer asked the captain “Right? Left?”, perhaps to ascertain in which direction the aircraft should be turned. Although at the time the aircraft was turning left, by then the rate of turn had gradually reduced, and the aircraft finally attained a heading of about 040 degrees.

2.4.3.2 Flap Over-speed

Throughout this time the aircraft was accelerating rapidly under TOGA power. At 1929:41 the Master Warning (a continuous repetitive chime) sounded, for flap over-speed, with an ECAM indication in red:

<u>OVERSPEED</u>
–VFE ……………………………… 185

The V_{FE} corresponded to the maximum speed for actual flap configuration (which in this case Flap 3). The V_{FE} is displayed on the air speed indicator as a red/black strip on the right side of the air speed indicator.

In responding to the situation of a flap over-speed, there are a number of possible courses of action available to the flight crew. These are:

a. Increase pitch attitude
b. Retract flaps

c. Reduce thrust
d. Extend speed brakes
e. Any suitable combination of a, b, c and d.

A suitable response depends on many factors (e.g.: aircraft configuration, phase of flight, height above the ground, ATC clearance, presence of other air traffic) and it is the captain's discretion to take appropriate action.

The first officer called at 1929:42 "speed, over-speed limit" and reminded the captain (at 1929:50) "Speed checks, flaps three". At 1929:52 the captain asked for "Flaps up". He did not increase the pitch attitude. Being at a go-around stage, he could not have reduced the thrust or extended the speed brakes.

The A320 ECAM does not suggest a corrective action to the flight crew in the case of a flap over-speed situation. The procedure to follow depends on many factors. It is therefore a matter of airmanship to decide on the appropriate action in the prevailing operational circumstances.

However, at 1929:43, at a height of 1058 ft AGL, the captain applied a nose-down side-stick input that was held for approximately 11 seconds. At 1929:48 the captain pressed the take-over pushbutton on his side-stick and held it for four seconds. This action was probably instinctive. Since the first officer was not using his side-stick, this action of the captain did not have any effect. During the 11 second nose-down side-stick input, the highest deflection of the captain's side-stick was 9.7 degrees. The side-stick was not re-centred during this 11 second period. As a result of this input, the aircraft pitched down to the maximum allowable angle of 15 degrees.

The most likely reason for the 11 second forward side-stick input by the captain (beginning at 1929:43) was that it occurred in response to his strong (but false) physical sensation that the aircraft was *pitching up* (see sections 2.4.4 and 2.4.5). Even though the aircraft's instruments were displaying its true pitch attitude, this information was not utilised by the captain in that he did not respond to it, even if he had perceived it. It was effectively this nose-down side-stick input that set in train the final sequence of events leading to the accident.

2.4.3.3 Ground Proximity Warning

While the captain was dealing with the flap over-speed situation, the first GPWS "sink rate" voice warning sounded at 1929:51 following the aircraft's response to the captain's nose-down side-stick input. At 1929:52, the next phase of the GPWS voice warning, "whoop, whoop, pull up" sounded, and continued every second until impact at 1930:02.

With the GPWS "sink rate" alert at 1929:51 (when the aircraft pitch was 12.7 degrees nose-down), there should have been an instant response from the captain, "Pull up to full back stick and maintain", in accordance with the SOP. The A320 FCOM further states, "During night or IMC (instrument meteorological conditions), apply the procedure immediately. Do not delay reaction for diagnosis"; and "GPWS response procedures are 'memory items' that are to be applied without referring to manuals or checklists" (refer to section1.17.3.7). However, the captain did not respond to either the initial GPWS "sink rate" alert or the subsequent "whoop, whoop, pull up" warnings. As noted in sections 1.16.1 and 1.16.2, the recovery study and simulator trials conducted as part of this investigation showed that if the captain had executed the response to the GPWS warning in accordance with the SOP, recovery was still possible.

However, at 1929:55 the captain made an 11.7-degree nose-up side-stick input (effecting an upward pitch change by about 6.7 degrees), which was less than the maximum capability of 16 degrees and the aircraft continued to descend. The last recorded value in the FDR was 'a nose down pitch of 6.3 degrees'. The '11.7-degree nose-up side-stick input' does not appear to have been made in response to the GPWS warning. The FDR recordings indicate that the captain's side-stick inputs, at about this '11.7-degree nose-up input', were similar to his earlier pattern of side-stick inputs during the orbit. As well, the CVR showed that neither the captain nor the first officer made any verbal response to the GPWS warnings before the impact. Instead, they continued to comment "gear up", and "flaps all the way (up)". Although the GPWS warnings indicated a grave and imminent threat to the aircraft, and continued to sound every second until the end, the CVR did not reveal any evidence that this dangerous situation was recognised by either the captain or the first officer.

If a captain does not respond to the first few GPWS warnings, the SOP is the first officer should assume that the captain is incapacitated, and take control of the aircraft. However, as stated in the paragraph above, in this case it appears that both the flight crew, the captain as well as the first officer, did not comprehend the criticality of the aircraft's attitude and increasing proximity to the ground.

2.4.4 Spatial Disorientation

The cockpit view calculations supported by the final flight path study indicate that all external visual cues were lost (at about 1929:41) as the last lights on the ground passed out of sight under the nose of the aircraft. The nose-down side-stick input by the captain commenced at 1929:43. At this point in time the aircraft was heading into an area of complete darkness. These conditions are conducive to the incidence of the somatogravic illusion. In this illusion, the absence of visual cues combined with rapid forward acceleration creates a powerful pitch up sensation.

The somatogravic illusion has been identified as a significant factor in numerous dark night take-off/go-around accidents. In these accidents the aircraft involved were typically accelerating into an area of total blackness. Under such conditions the somatogravic illusion induced by the aircraft's acceleration under TOGA power causes the pilot to perceive that the aircraft is pitching up, and he responds by making a 'nose-down input' on the controls. As a result, the aircraft descends and thereafter flies into the ground or water. (Refer to Appendix E).

2.4.5 Perceptual Study by the NAMRL

As stated in section 1.18.1, using the FDR data from the flight GF-072, a perceptual study was conducted at the US Naval Aerospace Medical Research Laboratory (NAMRL), Pensacola, Florida, USA (the full report is at Appendix E). The study showed that, at the time of the captain's forward side-stick input at 1929:43, he would have been experiencing a pitch up sensation of about 12 degrees. The application of forward side-stick input by the captain for 11 seconds resulted in the aircraft pitching down to an angle of 15 degrees (which is the maximum pitch down angle allowed by the A320 flight control system). This would have almost cancelled out the perceived pitch up sensation, and the flight crew probably believed they were in near level flight.

However, as noted in section 2.4.3.2, the cockpit instruments were displaying the true pitch attitude of the aircraft. The captain, as pilot flying, did not utilise this source of information, possibly he did not consciously perceive the information from the aircraft instruments. The CVR showed, at that time the captain's attention was focused on dealing with the flap over-speed warning.

2.4.6 Information Overload

The circumstances in the cockpit, and the behaviour of the captain, indicated that at this time (1929:41) the captain was probably experiencing information overload.

While there are a number of theories of human information processing, one characteristic that they all share is the concept of some form of overall central limitation on the rate at which humans can process information. This may take the form of a 'bottleneck', a pool of limited attentional resources, or an 'executive controller', supervising and co-ordinating multiple information processing resources.

However, while the underlying more esoteric theoretical issues continue to be investigated, the research carried out over the last 50 years or so, combined with actual operational experience has provided a practical first order working model of the fundamental capabilities and limitations of human information processing. This model is applicable to 'real world' situations, such as the analysis of human performance in complex socio-technical systems, accident investigation and training. Some key aspects of the model are briefly described as follows:

At the conscious level, the human brain functions as if it were a single channel information processor of limited capacity. Under conditions of information overload, responses fall into one or more of the following categories:

Omission	- ignore some signals or responsibilities.
Error	- process information incorrectly.
Queuing	- delay responses during peak loads; catch up during lulls.
Filtering	- systematic omission of certain categories of information according to some priority scheme. This can lead to the focussing, or 'channelling' of conscious attention on one element of a task, or situation, to the exclusion of all others.
Regression	- reversion to a previously over-learned response pattern.
Approximation	- make a less precise response.
Escape	- give up, make no response.

High levels of stress and anxiety can increase these effects. The situation had progressively deteriorated from the time of high speed initial approach, and the subsequent actions not achieving the desired results. It is also probable that the captain's level of stress and anxiety had progressively increased as the initial approach, and then the orbit, did not go as he had intended.

The captain visually flew an unplanned and unpractised manoeuvre; at low altitude with negligible external visual references; and in a high drag aircraft configuration. Following this orbit, the captain commenced to go-around at 1929:10. His immediate attention was then focussed on the go-around procedure, performing the checklist, and at 1929:33 also upon querying the instructions from ATC. Then, at 1929:41, the aural Master Warning (for flap over-speed) sounded, and his attention was concentrated on dealing with the flap over-speed situation.

All these factors combined to create an extended time period of very high workload for this captain, as well as the first officer, which progressively increased following the initiation of the orbit up to the time of the accident.

Under this very high workload and stressful situation, and with his conscious attention focused on the flap over-speed in the last moments before impact, the captain did not possess sufficient spare information processing capacity to perceive and respond to the information from the aircraft's instruments. Information from the instruments was *filtered* out. The overall lack of situational awareness demonstrated by the captain was evidence of *information overload* on the part of the captain.

The situation clearly raises important training issues. As described earlier, one of the consequences of information overload is the filtering out of categories of information according to some priority scheme. This phenomenon is often described as 'load-shedding'. An important objective of flight training is to ensure that, in situations of potentially very high workload, such as critical emergencies, the tasks most vital to the survival of the aircraft are accorded the highest priority by the crew. When this priority system is incorrect or inappropriate, that situations arise in which pilots concentrate on non-critical tasks, and filter out, or shed, critical information essential to the safety of flight, sometimes leading to accidents.

2.4.7 Controlled Flight Into Terrain (CFIT)

Even though GPWS warnings sounded every second from 1929:51, both flight crew did not respond to those critical warnings. Instead, during this period the captain was concentrating on dealing with the 'flap over-speed' situation. At this stage, the flap over-speed was not a critical emergency item[56], as it would not have endangered the aircraft. The GPWS warning indicated a far greater danger. However, for the reasons discussed above, the GPWS warnings were not responded to, and the flight crew concentrated their attention on the comparatively low priority flap over-speed situation.

To ensure that GPWS responses are accorded top priority, and that they are

[56] In accordance with Airbus Industrie clarification, the flap over-speed warning on Airbus A320 aircraft is related to torque limitations of the flap drive system.

sufficiently practised, or over-learned, so that they become automatic[57], a specific GPWS training programme is essential. The GPWS system was originally introduced as a defence against CFIT accidents, a category of accident that still accounts for the greatest number of airline fatalities each year.

The Flight Safety Foundation study of CFIT accidents, referred in section 1.18.2, has identified several factors that frequently appear in CFIT accident reports. These are: night and limited visibility conditions; terrain not observed until just before impact; loss of horizontal or vertical situational awareness; flight crew uncertainty about altitudes; and unstabilised approach. Nearly all these factors were present in the accident to GF-072.

The Gulf Air's CFIT training programme is discussed in section 2.8.2.

2.4.8 Air Traffic Control Issues

When GF-072 was on its VOR/DME approach for Bahrain Runway 12, at about the FAF (1926:08), the ATC (Tower Controller) had cleared the aircraft to land on Runway 12 (see Table 8 in section 2.4.1). Although the captain told the first officer at 1926:37 that he was "visual with the airfield", the ATC was not aware of this information. The next call the ATC received from GF-072, transmitted by the first officer, was at 1927:25 (at about the missed approach point) "requesting 360(-degree orbit) to the left". The request was immediately approved by the ATC at 1927:29.

This request was for a non-standard manoeuvre. The ATC "approved" the request, as there was no conflicting air traffic (aircraft) in the area. However, the ATC was not aware that GF-072 was "visual with the airfield", and in addition, GF-072 had not cancelled the instrument flight rule (IFR) condition. Consequently, the correct course for the ATC would have been to ask GF-072 to carry out a standard missed approach procedure; that is: "Climb on heading 121 degrees to 2500 ft (2494 ft AGL), then turn right to rejoin holding, or as directed". (see Figure 1: Instrument Approach Chart Bahrain Runway 12 VOR/DME). For the other analysis, refer to sections 2.4.2 and 2.6.

The Local ATS Instructions (LATSI) at Bahrain did not stipulate specific guidance to the controllers for addressing a request for such a non-standard manoeuvre. When there is no conflicting air traffic, the ATC may use the second part of the missed approach procedure "or as directed". However, in such a case an element of safety responsibility would be shared by the ATC. Hence, a request for a non-standard manoeuvre should only be approved by a controller after he/she has ascertained that the flight was "visual", and with an advice to climb to at least MSA (minimum sector/safe altitude), which in this case was 1500 ft, before executing any manoeuvre.

After the 'orbit', when GF-072 reported 'going-around' at 1929:08, the ATC did

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[57]. In general, overlearned behaviours are described as being elicited 'automatically' (i.e.: without conscious, higher level processing). Such 'automatic' actions can be completed rapidly without higher level processes involved in decision making and response selection.

take a proactive role and asked the flight crew "would you like radar vectors for final (approach) again?". The vectors were subsequently provided to GF-072. This proactive role by the ATC was a commendable action.

2.5 Non-adherence to Standard Operating Procedures

Regardless of the specific circumstances described above, which directly resulted in the loss of the aircraft, the accident could have been prevented if the pilot flying (PF) had adhered to SOPs. Section 2.4 describes a series of non-adherences to SOPs; particularly during the approach and final phases of flight, to name some:

- During the descent and the first approach, the aircraft had significantly higher speeds than standard.
- During the first approach, standard 'approach configurations' were not achieved, and the approach was not stabilised on the correct approach path by 500 ft.
- When the captain perceived that he was "not going to make it" on the first approach, standard go-around and missed approach procedures were not initiated.
- Instead, the captain executed a 360-degree orbit, a non-standard manoeuvre close to the runway at low altitude, with considerable variations in altitude, bank angle and 'g' force.
- A 'rotation to 15 degrees pitch up' was not carried out during the go-around after the orbit.
- Neither the captain nor the first officer responded to hard GPWS warnings.
- In the approach and final phases of flight, there were a number of deviations of the aircraft from the standard flight parameters and profile.
- During the approach and final phases of flight, in spite of a number of deviations from the standard flight parameters and profile, the first officer (PNF) did not call them out, or draw the attention of captain to them, as required by SOP's (see sections 1.17.4.1 and 2.6.2).

A "briefing" is an SOP carried out by a captain before specific phases of flight; such as descent, approach, landing, take-off, etc.; to ensure that all flight crewmembers are aware of their functions and know what to expect during the forthcoming phase of flight. As noted in section 2.4.1, there was no evidence of any "approach briefing" having been carried out by the captain on the 30-minute recording of the CVR. In the absence of any other evidence, it could not be established whether such a briefing was carried out prior to that time. There was also no evidence on the CVR that the possibility of a non-standard low-level orbit had been briefed as a contingency plan, should the approach not go as intended.

2.5.1 Accident Prevention Strategies

A Boeing analysis of commercial jet aircraft accidents over a ten year period from 1982 to 1991[58] aimed to identify and define "accident prevention strategies"

[58] Research published by the Boeing Commercial Airplane Group entitled "Understanding Flight Crew Adherence to Procedures: The Procedural Event Analysis Tool (PEAT)". (Information on this research is available on the following web site: http://www.boeing.com/news/techissues/peat).

which could have prevented each hull loss. An “accident prevention strategy” refers to a particular course of action, or intervention, which, had it been implemented, would have stopped the accident from occurring. From this research, published in 1993, it was found that the accident prevention strategy, which could have prevented the greatest number of accidents was *“the adherence of the flying pilot to SOP’s”*.

The analysis found that “Almost 50% of all hull loss accidents could have been prevented by this strategy.” (Graeber and Moodi, 1998) This figure becomes even higher if the next two most frequently identified strategies are included, these being *“other procedural considerations”* and *“non flying pilot adherence to procedures”*. In summary, the top three accident prevention strategies were all concerned with *adherence to SOP’s*.

Similar findings were also published in 1998 by the Civil Aviation Authority of the United Kingdom (UK CAA). In its *Global Fatal Accident Review, 1980-1996*[59], non-adherence to procedures was identified as a key factor in accident causation.

Complementary data also come from a preliminary analysis by the Australian Transport Safety Bureau (ATSB) of over 2000 minor incidents involving high capacity scheduled airline operations. This showed that in 84% of cases, *“adherence to procedures”* prevented these relatively minor incidents from developing into more serious events (ATSB, 2001).

2.5.2 Reasons for Non-adherence to SOPs

Boeing researchers Graeber and Moodi (1998) point out that the reasons why flight crew do not comply with procedures are “poorly understood”, and that “they may range from ambiguously written or poorly understood procedures to inadequate training, design issues, incompatible air traffic environments, unexpected operational situations, or bad judgement”.

Similarly, if the procedures are there, but crews are not sufficiently trained in their application, they are less likely to comply with them.

If procedures are poorly designed, and, for example, are incompatible with the demands of high-density air traffic environments, it may prove operationally difficult for crews to adhere to them. If an operational situation arises which is not anticipated, crews may not comply because they are uncertain of what procedures might be appropriate to that unexpected situation. Finally, bad judgement may be a factor in non-adherence to SOP’s. A decision may be made not to comply with, or violate, SOP’s. Such a decision indicates bad judgement on the part of the crew. Violations are discussed in section 2.5.3.

The FAA Human Factors team in its 1996 report acknowledged the critical significance of procedural deviations in its recommendation:

[59] Civil Aviation Authority, *Global Fatal Accident Review, 1980-1996*. CAP-681, United Kingdom, 1998.

"The FAA should assure that analyses are conducted to better understand why flight crews deviate from procedures, especially when the procedural deviation contributes to causing or preventing an accident or incident"

In the present accident, had the aircraft been operated in accordance with SOP's, this accident would not have occurred. One of the objectives of this analysis is to understand why the procedures were not adhered to.

2.5.3 Errors and Violations

The Reason Model uses the term 'unsafe acts' to refer to decisions or actions which have an immediate effect on the safety of the operation. Unsafe acts can be further categorised in terms of 'intended' and 'unintended' actions. Intended actions can be either mistakes, or violations (see Figure 10).

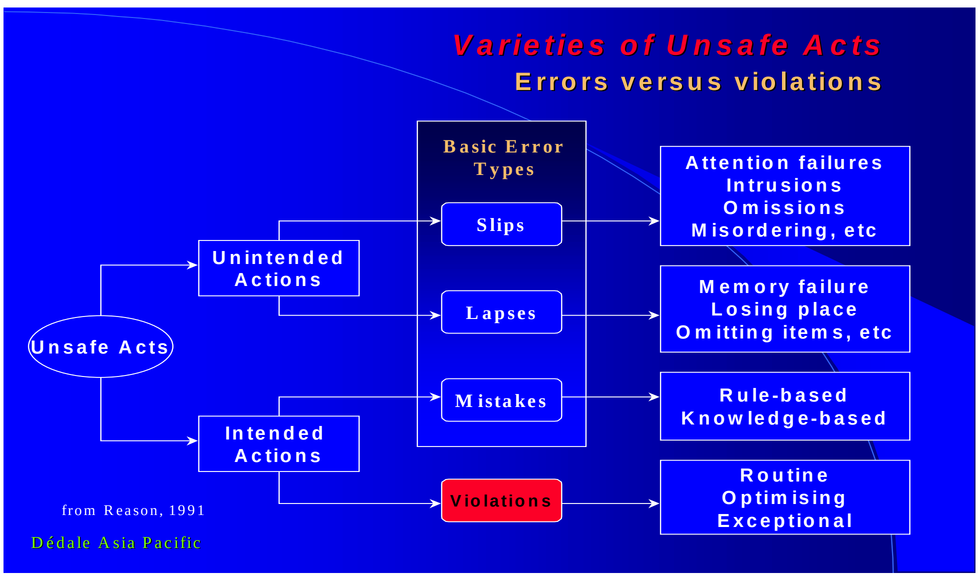

Figure 10: Varieties of Unsafe Acts

Violations are intentional deviations from rules or procedures. There are a number of different kinds of violation, and Hudson[60] describes them as follows:

Unintentional non-compliance: unintentionally breaking the rules.

Routine violation: frequent, known and condoned, 'everybody does it'.

Optimising violation: breaking the rules to try and do things better.

Situational violation: adapting to the problems in the workplace.

Exceptional violation: totally unexpected non-adherence to procedures.

[60] Hudson, 2000, Proceedings of 11th Airbus Industrie Human Factors Symposium, Melbourne, Australia.

Research has identified a number of key factors which predict the occurrence of violations. In other words, if these factors are present, it is probable that violations of rules and operating procedures will occur. Hudson describes the main predictors of violations as follows:

Expectation:	expectation that rules will have to be bent to get the job done.
Powerfulness:	the feeling that one has the ability to do the job without slavishly following the procedures.
Opportunities:	seeing opportunities that present themselves to take short-cuts, or 'to do things better' than the existing procedures allow.
Planning:	inadequate work planning and advance preparation, leading to working on the fly, and solving problems as they arise.

These concepts are applied in the following analysis.

2.6 Flight Crew Performance

2.6.1 The Captain's Performance

In the accident to GF-072, a number of SOPs were violated by the captain (refer to sections 2.4 and 2.5). These non-standard actions appeared to have involved a combination of factors described in unsafe acts (see section 2.5.3). For example, when the first approach unexpectedly turned out to be unsuccessful, the captain attempted to solve the problem by taking an ad hoc decision to execute a non-standard and unplanned manoeuvre (an orbit). This was a course of intended action, which involved poor judgement, non-adherence to SOP's, and in Hudson's terms an *'exceptional'* violation. It was an 'unsafe act' as described in section 2.5.3, which had an immediate adverse effect upon the safety of the system. The captain performed this unsafe act without prior briefing to his first officer, and in the absence of any valid operational necessity, such as an unexpected emergency.

Hudson argues that the combination of violation plus error is a *'lethal cocktail'*. This is because the occurrence of error is independent of a person's intention. In other words, whether one intends to comply with SOP's, or whether the intention is to violate SOP's, the potential for human error is the same in each case. SOP's have been developed largely on the basis of operational experience. Consequently, by their very nature SOP's provide a margin for error. Once they are violated, that margin for error is either reduced, or lost completely.

Hudson's view is well illustrated by the present accident. There were the violations of SOP's described above, which resulted in the aircraft and the flight crew being placed in a situation conducive to spatial disorientation. These were coupled with a critical action by the captain, i.e.: the 11 second nose-down sides-tick input at 1929:43, followed by his lack of response to the GPWS warning. These commissions and omissions, precipitated by the somatogravic illusion, in combination with an operational situation which imposed very high mental workload on the captain, resulted in the accident. This was the '*lethal cocktail'* in action.

These events raise two critical questions: Firstly, why were the decisions made by the captain to violate the SOP's? Secondly, why was there no challenge, no questioning, nor even any comment, from the first officer when these clearly non-standard decisions were made by the captain?

The captain's sudden, unplanned, decision to execute an orbit, rather than to carry out a go-around and missed approach, was apparently made to avoid the necessity for a standard missed approach procedure. A missed approach is a perfectly routine safety procedure, although in practice it is a relatively rare occurrence. However, there could be reasons why a captain might be reluctant to carry out such a procedure.

For example, a captain might be unwilling to carry out a go-around or a missed approach if he perceives that his company regards conducting such action in an unfavourable light. As noted in section 1.17.1.1, at the time of the accident, performing a go-around would require the subsequent submission of an Air Safety Report, describing the circumstances of the event. Although Gulf Air stated that its policy was not to take action against any pilot who had conducted a missed approach, it was apparent that, at the time of the accident, a perception existed on the part of some company pilots that a missed approach would be regarded unfavourably by company operational management.

As a post-accident safety initiative, Gulf Air issued a Fleet Instruction, referred in section 1.17.11.5, which states: *"All pilots are further assured that no disciplinary action whatsoever will be taken against any crew that elects to carry out a go-around for safety-related reasons, including inability, for whatever reason, to stabilise an approach by the applicable minimum height".*

Another factor contributing to the non-adherence of SOPs might be that a company may not strongly emphasise the importance of, and the need to adhere to, SOPs. In such a situation, a captain's non-adherence to SOPs would be consistent with his organisational environment. Interviews conducted by the Operations/Human Performance Group indicated that while most pilots stated that there was a high level of compliance with SOP's by personnel within the company, there was also evidence that some pilots did not always do so. The interviewees expressed differing opinions about performing an orbit. The flight data analysis system would normally identify the level of compliance. However, at the time of accident the company flight data analysis system was not functioning satisfactorily (refer to section 2.9.1).

Yet another factor may be that a captain might feel that, if he has to execute a missed approach, his flying ability might be seen to be lacking in the eyes of a relatively junior first officer. in the present case, the CVR showed that earlier in the flight (at 1924:38), the captain was demonstrating his knowledge of the A320 systems to the first officer. This indicates that the captain was, understandably, keen to ensure that a relatively less experienced first officer should have every confidence in his abilities as a captain to operate the aircraft, and that the first officer could learn a lot from flying with him.

In this context, another factor is the potential damage that the captain perceived to his own self-esteem and his own self-expectations or self-image as a result of his unsuccessful approach. This is evidenced on the CVR by the captain's use of expletives at 1928:57, when he realised he had overshot the runway centre-line. This can be inferred to be a manifestation of his frustration with his own performance. Similarly, the captain clicking his tongue at 1929:04, just before he asked the first officer to tell ATC that he was going-around, may also have been a sign of such frustration.

The evidence indicates that all of the above factors help explain the actions of the captain during the final phases of the flight.

2.6.2 The First Officer's Performance

The first officer performed his routine role; i.e.: of communicating with the ATC, reading the checklist, and carrying out the checks. However, the CVR indicates that he played little effective part in flight deck management and decision making. At no stage did he raise any issues with, or question the captain's decisions, even though the captain performed non-standard procedures and manoeuvres.

In accordance with the A320 FCOM, the non-flying pilot (PNF), in this case the first officer, is required to make standard call-outs during the final approach, particularly in respect of any deviations from the standard flight path (see section 1.17.4.1). Although there were a number of deviations from the standard on the final approach, the CVR shows little evidence of the first officer either calling out such deviations or challenging them. He did not draw the captain's attention to the aircraft exceeding the operational limits specified in the SOPs (see section 2.5). He did not point out to the captain his non-adherence to SOPs, such as during the approach profile, go-around and missed approach.

Evidence from the training records of the first officer indicated that he was seen as 'shy' and 'unassertive', and that his operational performance overall was marginal. Although he was assessed as competent in some areas, his training records indicated that he had difficulties in meeting the required standards overall. Instructors made comments such as, he was 'behind the aircraft'. On one occasion he became 'disoriented' going into Bahrain. This first officer was unlikely to speak up and challenge a captain's authority. It is also likely that the captain's overt demonstration of his knowledge earlier in the flight (as seen from the CVR recording) may have further dampened the first officer's tendency to speak up.

However, to be fair to this relatively junior first officer, it must also be very strongly emphasised that at no point in the approach and final phases of the flight did the captain consult him or include him in the decision making process. The first officer was a valuable operational resource available to the captain, which he did not use effectively.

2.6.3 Flight Crew Performance as a Team

Crew performance is the outcome of a complex interaction between the individual flight crewmembers. Provided that their teamwork is effective, the strengths of one crewmember can compensate for weaknesses in the other.

The worst-case situation is when both flight crewmembers are relatively inexperienced, and in addition they do not work together effectively as a team. In such a case, the overall crew performance level is poor. The accident to GF-072 was an example of such a situation, although both flight crewmembers were qualified and meeting minimum requirements. The evidence from the CVR showed little evidence of effective teamwork.

As noted in sections 2.6.1 and 2.6.2, the captain did not effectively use the first officer, a valuable operational resource available to him. In addition, the first officer did not effectively discharge his responsibilities, in the management of aircraft flight operations, of alerting the captain about the deviations from the standard flight parameters, and to respond to hard GPWS warnings. To all intents and purposes, the captain appeared to conduct this part of the flight effectively as a single pilot. The first officer did not participate in the role of decision making, but rather assumed a subordinate role, being primarily responsible for communications, calling out checks and conducting checklist procedures under the directions of the captain. The benefits of CRM in ensuring effective performance of flight crew as a team are discussed in section 2.7.

2.6.4 Flight Crew Fatigue Factors

A routine question for the analysis of an accident such as that to GF-072, is whether the performance of the flight crew showed evidence that it had been affected by fatigue. In considering this issue, it must first be determined if the flight crew were adequately rested before the flight, and, secondly, whether their behaviour showed characteristics consistent with the known effects of fatigue on performance.

As detailed in Section 1.5.3, the crew's 72 hour history showed that while they were awake until a late hour on the night before the flight, as their scheduled departure was in the afternoon of the next day, they had ample opportunity to obtain adequate rest before they commenced duty.

Secondly, the evidence of their behaviour on the flight itself, as recorded on the CVR, did not indicate the effects of fatigue. The flight operations appeared normal. There were no verbal expressions of tiredness, no behavioural indications of fatigue - such as memory lapses, delayed or inappropriate actions, no failures to respond to communications, no incorrect perception of radio communications from ATC, and no signs of cognitive impairment on the part of either pilot.

On the contrary, the captain's conversation at time 1924:38, in which he explained some of the aircraft systems to the first officer, showed no evidence of fatigue. He appeared to be alert.

However, based on the available evidence, it could not be determined whether and to what extent the flight crews' performance was affected in any way by fatigue and decreased alertness.

2.7 Crew Resource Management (CRM)

Over many years numerous serious civil airline accidents have resulted from inadequate flight crew performance, often involving individual crewmembers with outstanding operational records. The collision between two Boeing B747 aircraft at Tenerife in 1977, is a prime example[61]. In this accident, which remains aviation's worst disaster, the KLM captain who commenced take-off without a clearance, and whose aircraft collided with the US airline Pan Am's B747, which was still on the runway, was one of the Dutch airline's most senior and best pilots.

Accidents such as this, which involved the failure of flight crews to perform effectively as teams, led to the development of training programmes known as crew resource management, or 'CRM'.

The US FAA defines CRM as the "utilisation of all available human, informational and equipment resources toward the effective performance of a safe and efficient flight. CRM is an active process by crewmembers to identify significant threats to an operation, communicate them to the pilot-in-command (PIC), and develop, communicate and carry out a plan to avoid or mitigate each threat. CRM reflects the application of human factors knowledge to the special case of crew and their interaction". CRM is a practical application of human factors knowledge.

ICAO has long recognised that basic education in human factors was needed. This led ICAO to include this need into the training and licensing requirements in Annex 1 (1989), and Annex 6 (1995). Amendment 21 to Annex 6 (1995) promulgated a standard regarding initial and recurrent training in human factors knowledge and skills for flight crews. That recognises the value of CRM training as a critical element in the operational safety culture of airline operations. ICAO has promoted the adoption of CRM training programmes in all contracting States.

Since they began in the USA in the early 1980's, CRM training programmes have been introduced throughout the international aviation industry, and have undergone continuous development over the last 20 years. They have now progressed through five 'generations' (Helmreich, 1999).

As discussed in section 2.5 , if the SOPs had been adhered to, the accident to GF-072 could have been prevented. A contributing factor to this non-adherence was the lack of CRM in the cockpit. In post accident analyses of the CRM aspects of flight crews' performance, there is often a pattern of communication recorded on the CVR, which can be analysed and assessed against good CRM practice. However, in the case of GF-072, there is very little relevant communication to analyse. As noted earlier, the captain did not utilise effectively the first officer, a valuable resource. The first officer performed routine procedural functions, and made little significant contribution to the conduct of the last critical phases of the flight. His lack of comments throughout this period shows that, whatever he might have thought internally, he deferred to all of the captain's decisions and actions, even though they involved the violation of SOP's.

[61] Subsecretaria de Aviacion Civil, Spain (1978). KLM, B-747, PH-BUF and Pan Am B-747 N736 collision at Tenerife Airport Spain on 27 March 1977. Madrid, Spain: Author.

The interaction of these two quite different flight crew may have created a steeper trans-cockpit authority gradient, resulting in the first officer being even less likely to participate in operational decision making as compared to situations where he was paired with a captain with a more participative management style.

One of the goals of CRM training is to provide crewmembers with the tools to foster co-operative collaborative teamwork and overcome counterproductive styles of leadership and group interaction. Such tools include assertiveness training for first officers, and participative management training for captains.

The boundaries and content of CRM training have now extended well beyond the original limited domain of group dynamics within the crew. Contemporary CRM programmes now cover much broader human factors areas, including human performance capabilities and limitations, together with issues such as human computer interaction, systems safety, threat and error management, and the integration of Line Operations Safety Audits (LOSA) with CRM training.

However, regardless of the possible underlying factors, the precise influences of which can only be speculated upon, the evidence shows that the CRM in the cockpit of GF-072 was ineffective, and that this contributed to the non-adherence to SOP's by the flight crew, which initiated the sequence of events which led to the loss of the aircraft.

2.8 A320 Flight Crew Training in Gulf Air

2.8.1 CRM Training

As noted in section 1.17.4.2, under the Sultanate of Oman regulations (CARs), there had been a requirement that Gulf Air provide a CRM programme since June 1999. A company had been selected to develop a CRM programme for the airline, and it appears that some training of facilitators had taken place. However, progress was slow, and at the time of the accident there was no formal CRM training programme within Gulf Air. The accident to GF-072 was consistent with that organisational deficiency.

Since the early 1980's many airlines have implemented CRM programmes for sound commercial and safety reasons in the absence of formal regulatory requirements. Such actions represented prudent safety practice on the part of these companies. As stated in section 1.17.4.2, there had been an in-house Gulf Air CRM programme from about 1992 until late 1996 or early 1997. However, it appears to have been discontinued when there was a change of management. The Acting Manager of Human Factors, at the time of the accident, stated that his predecessor had resigned because of frustration with his lack of success in attempting to re-establish the company CRM programme.

In the ICAO Human Factors Training Manual (ICAO, 1998), it is pointed out that "… the development and implementation of CRM and Line Orientated Flight Training (LOFT) takes about one year, since it involves the collection and interpretation of data. Furthermore, training an entire airline pilot population in CRM may take several years, depending upon the size of the population" (p. 2-2-1).

However, if the worth of operational benefits of a CRM training programme had been recognised by senior management at the time that the in-house course started in 1992, Gulf Air could have had a mature and well established CRM programme in place some years before the accident to GF-072. The continued existence of a CRM course at that time would have been consistent with contemporary industry best practice.

The value of CRM training to operational safety should, and could, have been recognised by the company a long time ago.

Gulf Air has reported that a generic CRM ground school programme for the flight crew and cabin crew is in place since the accident in conjunction with M/s Dedale Company of France. However, as of May 2001 the A320 type-specific simulator part of the CRM training and Line Oriented Flight Training (LOFT) were yet to be implemented. Gulf Air further reported that these are expected to be introduced along with the annual recurrent CRM training programme during the year 2002.

2.8.2 A320 CFIT Training Programme

For over twenty-five years the aviation industry has recognised the value of specialised CFIT training in preventing this type of accident which typically occurs in the descent, approach and landing phases of flight. CFIT accidents continue to account for the highest proportion of fatalities annually in commercial aviation. The Gulf Air Operations Training Manual gives the details of the CFIT training programme, and there is a large amount of information and training material readily available on this subject. However, in actual practice, the CFIT training in the A320 fleet in Gulf Air was severely limited at the time of the accident to GF-072 (refer to section 1.17.2.2):

(a) A once only CFIT briefing was conducted at the time of conversion training.
(b) A once only CFIT questionnaire was completed by each pilot during the simulator part of initial CFIT training.
(c) The A320 designated examiners/simulator instructors were reminded on Base-checks by a memo on 20 April 2000: “each pilot should complete TCAS, CFIT and windshear exercises …”.
(d) The content of the CFIT simulator training was left to the discretion of the instructor, CFIT was a box to be ticked on the training records in the case of recurrent training. However, although the training may have been accomplished, there was no detailed syllabus for CFIT training.

2.8.3 GPWS Pull-up Demonstration and Response Procedures

Airbus Industrie’s A320 Normal Course syllabus includes a GPWS pull-up demonstration. However, there was no similar syllabus for Gulf Air, and no requirement to execute such a demonstration for Gulf Air’s A320 fleet (refer to section 1.17.2.2).

The importance of a specifically 'focussed GPWS response training' has been recognised in the industry, and has been emphasised in accident investigation reports. This is illustrated by two safety recommendations from the US NTSB:

<u>Recommendation A-81-019</u>: The NTSB recommends that the Federal Aviation Administration instruct all air carriers to include in their flight crew procedures instructions which require an immediate response to the ground proximity system's terrain closure "pull-up" warning when proximity to the terrain cannot be verified instantly by visual observation. The required response to this warning should be that the maximum available thrust be applied and that the aircraft be rotated to achieve the best angle climb without delay.

<u>Recommendation A-81-020</u>: The NTSB recommends that the Federal Aviation Administration instruct air carriers to include in their initial and recurrent simulator training curricula situations involving radar controlled as well as non-controlled flight wherein ground proximity warning system alarms are given and flight crew response to those warning system alarms are evaluated.

The A320 FCOM states that the GPWS responses are memory items that are to be applied without referring to manuals or checklists (see sections 1.17.3.7 and 2.5.3). Airbus Industrie's publication on CFIT escape manoeuvres places a strong emphasis on a required single, immediate, instinctive pilot action to be carried out immediately in response to a GPWS warning (see section 2.4.3). This is made possible by the envelope protection afforded by the aircraft's fly-by-wire flight control system. However, Gulf Air's A320 training programmes have not shown evidence of strong emphasis on the GPWS response training (refer to section 1.17.2.2).

As noted in sections 1.16.1 and 1.16.2, the recovery study and simulator trials conducted as part of this investigation showed that if the captain had executed the response to the GPWS warning in accordance with the SOP, recovery was still possible. The SOP was: "a single, immediate, instinctive pilot action", and the 'full back stick and maintain' was as specified in the A320 FCOM. In addition, the recovery study showed that with a two second response time, a one second reaction time, and half back side-stick, the aircraft was recoverable from the altitude at which the GPWS aural warning commenced.

2.8.4 Objectives of Flight Crew Training

One of the main objectives of flight crew training is to ensure that the flight crew adhere to SOP's. As discussed in section 2.6, there was a series of instances of non-adherence to procedures in respect of GF-072, particularly in the initial approach, final approach, missed approach, and go-around phases. The non-adherence to the procedures by the flight crew of GF072 is evidence that the existing training regime in respect of the A320 flight crew did not achieve the above objective, at least not in the case of this particular flight crew.

2.9 Gulf Air's Organisational Factors

2.9.1 Flight Data Analysis

Flight data analysis is a proven means to conduct regular safety analyses. Regular analysis of the flight parameters recorded by flight recorders, such as the Digital AIDS Recorder (DAR), enables the study of trends in a wide spectrum of safety related areas of flight operations and maintenance practices. Such analysis provides valuable information indicating individual and general trends (such as: deviations from standard flight parameters, violations, etc.), that assists an airline in developing and updating its safety related policies.

As noted in section 1.11.3, the DAR from the accident flight was recovered in relatively good condition. However, no data had been recorded on the tape. A study of the airline's A320 DAR-analysis indicated that this was the also the case with some other aircraft. In summary, at the time of the accident, the flight data analysis system was not functioning satisfactorily. Non-availability of flight data analysis deprived the airline of a valuable safety analysis tool. As a post-accident initiative, the regulatory authority (DGCAM) is examining the working of Gulf Air's flight data analysis system, the outcome was not available as of August 2001.

2.9.2 Flight Safety Department

The ICAO Human Factors Training Manual states (paragraphs 2.5.9 and 2.5.10):

"From the simplest of perspectives, management's most obvious contribution to safety is in the allocation of adequate and necessary resources to safely achieve the production goals of the organisation."

Management should also ensure *"…the implementation, continued operation, and visible support of a company safety programme…The programme should be administered by an independent company safety officer who reports directly to the highest level of corporate management".*

As stated in section 1.17.1.1, since 1998 up to the time of the accident the Manager of Flight Safety had been the only person in his department. He did not report directly to the highest executive level within the company. This lack of resources within the flight safety department, and its inappropriate corporate status within the company was a serious organisational deficiency.

Gulf Air has participated in the six-monthly meetings of the IATA Safety Committee (SAC) for many years. The SAC is a highly valuable operational industry safety forum, at which the latest safety information is shared between airlines on a full, frank and open basis. This sharing of the most current information enables companies to take immediate action on safety issues, without having to wait for the publication of official reports or documentation. However, in the years preceding the accident to GF-072, Gulf Air did not attend SAC meetings. This greatly restricted the airline's awareness of new information and developments in areas such as accident investigation case studies, safety and risk management programmes, CRM and LOSA training, safety information systems, and safety management programmes.

As a post accident initiative, the Gulf Air flight safety department is receiving support from the new executive management, and has resumed participating at the SAC meetings.

2.9.3 Safety and Risk Management Programmes

The foregoing analysis has highlighted many latent organisational factors within Gulf Air that were present before the accident.

Factors such as inadequacy in operational training programmes, the lack of a CRM training, the lack of an integrated company wide safety and risk management programme, the unsatisfactory functioning of flight data analysis, the under-resourcing and lack of high-level corporate status of the flight safety department, have all been discussed.

There is an increasing awareness in aviation and other high technology industries about the cost-benefit factors in safety; i.e. the relatively low costs of introducing and maintaining a safety programme compared to the high costs of accidents and incidents, and that proactive investment in safety is a good business practice. Hence, a safety department is progressively seen as a profit centre rather than a cost centre. There is a growing realisation that safety and commercial goals are, in fact, compatible, and that a powerful business case can be made for the implementation of safety and risk management programmes.

2.10 Safety Oversight Factors

2.10.1 Role of the Regulatory Authority

The regulatory authority plays a critical role in maintaining the safety of the aviation system. A primary function of the authority is to formulate and set minimum standards for flight operations and airworthiness of aircraft. It is then the responsibility of the authority to ensure that these standards are maintained by operators. It does this by field surveillance and inspection of actual operations of the companies being regulated, and by audits of the systems, processes and procedures of those companies. This provides an independent means of quality oversight and control of the aviation system on behalf of the travelling public.

It is impractical for a regulator to achieve total surveillance of all the operations of a company. It must therefore aim to survey a sample of a company's operations which is representative of the totality of its operational standards and performance. For example, a regulator may aim to survey a particular percentage of the hours flown by an operator, having determined analytically that this percentage will provide a valid representation of the company's overall operational flying standards.

However, if this basic level of surveillance of an airline is not achieved, the regulatory authority may have no valid knowledge of the actual operational standards of the company, and thus be ineffective as a regulator. Furthermore, standards in the company may deteriorate without the regulator being aware of it. To be effective in its role, the regulatory authority must possess the human and financial resources necessary to carry out its mission. It must also have the specialist regulatory skills required, together with the operational expertise to match that of the companies for which it is responsible.

In addition, when deficiencies are identified, the regulator must have a sufficient legislative head of power to implement change and, where appropriate, to impose meaningful penalties to achieve regulatory compliance.

2.10.2 DGCAM, Sultanate of Oman

In the case of Gulf Air, the agency responsible for the regulatory oversight, of its flight operations is the Directorate General of Civil Aviation and Meteorology (DGCAM), Sultanate of Oman (see section 1.17.8).

As noted in section 1.17.8.1, a review of correspondence between DGCAM and Gulf Air revealed numerous letters citing a lack of compliance with CARs. The evidence indicated that in some safety areas, Gulf Air did not effect timely changes when problems were identified by DGCAM. The then POI stated that Gulf Air did not have a number of programmes required by the regulations, and in other areas it did not meet the regulations. These areas included CRM, quality management, safety awareness, surface contamination complete with required crew training, and the maintenance of crew records for flight duty and rest time limitations.

As stated in section 1.17.9, a special evaluation carried out by ICAO at the request of the DGCAM in October 1998 noted evidence of delayed or non-compliance with regulatory requirements, and opposition by the company to CAR 121. The ICAO review further stated that, except for isolated incidents, most of the infractions could be traced to inadequate supervisory oversight (within Gulf Air), rather than a deliberate disregard for the regulations.

The DGCAM was well aware of this situation, and had made numerous, but unsuccessful, efforts to correct it. As noted in sections 1.17.1 and 1.17.7, in its efforts to seek regulatory compliance, the DGCAM had imposed sanctions on the airline. These included revocation of ETOPS time, revocation of three-engine ferry flight approval, and crew licence suspensions. Despite these measures, Gulf Air did not implement many changes sought by the DGCAM.

A review of relevant information and documentation, covering approximately three years preceding the accident indicated that despite intensive efforts as described above, the DGCAM could not achieve compliance by Gulf Air with respect to some critical regulatory requirements, due to inadequate response by the operator.

2.10.3 Complementary Roles in Maintaining Safety

Regulatory authorities and airlines have complementary roles to play in maintaining the safety of the aviation system. Strong and effective regulators are in the interests of airlines because, as noted earlier, they provide an independent means of quality control in all aspects of airline operations. Conversely, an airline with a safety culture, which is strongly motivated towards compliance with the regulations, is in the interests of the regulator.

At the time of the accident, this situation did not exist in the case of the DGCAM and Gulf Air. This was primarily because the company was either not responsive, or slow to respond to the requirements of the regulatory authority; although the DGCAM was attempting to ensure regulatory compliance by Gulf Air.

2.10.4 Systemic, Structural and Organisational Issues

The fundamental systemic structural and organisational issues described above are all interrelated. They must therefore be addressed from a systemic perspective as an outcome of this investigation, for the sake of both the DGCAM and Gulf Air. The analysis of the accident to GF-072 indicates that the accident, in terms of the Reason Model, had major organisational aspects. Long standing, or latent systemic deficiencies contributed to make the accident possible.

The investigation showed that all of the latent organisational and management conditions that precipitated the accident to GF-072 were present long before the accident. They had been identified, and should have been rectified before it happened. If these deficiencies had not been rectified, similar accidents could occur again, for the same underlying systemic reasons.

The mutually complementary roles of the regulator and the airline need to be clearly recognised, legally defined, and be formally agreed upon between the parties to accomplish safety related regulatory compliance and foster a safety culture.

Perhaps most importantly, the regulator needs to review whether the resources, structures and processes necessary to ensure regulatory compliance are adequate; and the airline needs to rectify the systemic deficiencies.
