Foreword

The Kingdom of Bahrain is a signatory to the Convention on International Civil Aviation (Chicago, 1944). Article 26 of the Convention obligates the governments of countries that are signatories to the Convention to conduct investigations into aircraft accidents and incidents in their territories, which involve specific aircraft from other countries which are also signatories to the Convention.

The Kingdom of Bahrain applies the standards and recommended practices of Annex 13 of the Convention to all investigations of aircraft accidents and incidents. In doing so, the fundamental objective of the investigation is the prevention of aircraft accidents and incidents. The intention of this activity is neither to apportion blame, nor to assess individual or collective responsibility. The sole objective is to draw from this occurrence lessons that may help to prevent future accidents or incidents.

This document is based on the data collected on the circumstances of the accident, which then has been analysed for the investigation. The focus of the investigation of the tragic accident to GF-072 has been to establish what happened, to analyse how and why the occurrence took place, and from this analysis to determine what the occurrence reveals about the safety health of the aviation system. Such information is used to arrive at conclusions and make safety recommendations aimed at reducing or eliminating the probability of a repetition of the same type of occurrence, and where appropriate, to increase the overall safety of the aviation system.

ABBREVIATIONS

A/THR	Auto thrust
AAL	Above Aerodrome Level
ADD	Acceptable Deferred Defects
AGL	Above Ground Level
AIDS	Aircraft Integrated Data System
AIP	Aeronautical Information Publication
ALAR	Approach and Landing Accident Reduction
AMSL or amsl	Above Mean Sea Level
AOC	Air Operator's Certificate
AP/FD	Autopilot/Flight director
ARFF	Aircraft Rescue and Fire Fighting
ASR	Air Safety Report
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATSB	Australian Transportation Safety Board
ATP	Airline Transport Pilot
BEA	Bureau Enquetes Accidents
BOAC	British Overseas Aircraft Corporation
CAA	Bahrain Civil Aviation Affairs
CAMI	Civil Aeromedical Institute
CAR	Civil Aviation Regulations
CAVOK	Ceiling and Visibility OK
CBT	Computer Bases Training
CFIT	Controlled Flight Into Terrain
CG	Centre of Gravity
CLB	Climb
CP	Commercial Pilot
CPL	Commercial Pilot Licence
CPT	Cockpit Procedure Trainer
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
DAR	Digital Aids Recorder
DGCAM	Directorate General Of Civil Aviation & Meteorology, Sultanate of Oman
DME	Distance Measuring Equipment
ECAM	Electronic Centralised Aircraft Monitoring
F	Minimum speed at which the flaps may be retracted at takeoff/go-around
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FCOM	Flight Crew Operating Manual
FD	Flight Director
FDR	Flight Data Recorder
FMA	Flight Mode Annunciator
FMGS	Flight Management Guidance System
G	Gravitational Force
GAMCO	Gulf Aircraft Maintenance Company
Green Dot '0'	Engine out operation speed in clean configuration – best lift to drag ratio speed, corresponds to the final take-off speed
GPWS	Ground Proximity Warning System
HDG	Heading
hP	**Hecto-pascals (atmospheric pressure measurement unit)**

ABBREVIATIONS

IFR	Instrument Flight Rules
IR	Instrument Rating
LATSI	Local ATS Instructions
LDA	Landing Distance Available
LOFT	Line Orientated Flight Training
LOSA	Line Operations Safety Audits
LRV CLB	Lever Climb
MAC	Mean Aerodynamic Chord
MCDU	Multi Control Display Unit
MEL	Minimum Equipment List
MHz	Megahertz
MLG	Main Landing Gear
MMO	Maximum Operating Mach No
NAMRL	Naval Aerospace Medical Research Laboratory, Pensacola, USA
ND	Navigation Display
NDB	Non Directional Beacon
NOSIG	No significant change
NM or nm	Nautical Mile(s)
NTSB	National Transportation Safety Board
PAPI	Precision Approach Path Indicator
PEAT	Procedural Event Analysis Tool
PERF	Performance
PF	Pilot Flying
PFD	Primary Flight Display
PIC	Pilot-in-Command
PNF	Pilot Not Flying
POI	Principal Operations Inspector
S	Minimum speed at which the slats may be retracted at takeoff/go-around
SAC	IATA Safety Committee
SEP	Safety Emergency Procedures
SIC	Second In Command
SOI	Senior Operations Inspector
SOP	Standard Operating Procedures
SRS	Speed Reference System
TCAS	Traffic Alert and Collision Avoidance System
TOGA	Take off Go-ground
TSN	Time Since New
UTC	Universal Time Co-ordinated
V BUGS	Speed settings
V_1	Decision speed
V_2	Take-off safety speed
V_{APP}	Approach speed
VOR	Very High Frequency Omnidirectional Range
V_{FE}	Maximum speed with flaps extended
V_{LE}	Maximum speed with landing gear extended
V_{LS}	Minimum selectable speed
V_{MAX}	Lowest of V_{MO}, V_{LE} and V_{FE}
V_{MC}	Visual Meteorological Conditions
V_{MO}	Maximum operating speed
VR	Rotation speed

Executive Summary

Brief History of the Flight

On 23 August 2000, at about 1930 local time, Gulf Air flight GF-072, an Airbus A320-212, a Sultanate of Oman registered aircraft A40-EK, crashed at sea at about 3 miles north-east of Bahrain International Airport. GF-072 departed from Cairo International Airport, Egypt, with two pilots, six cabin crew and 135 passengers on board for Bahrain International Airport, Muharraq, Kingdom of Bahrain. GF-072 was operating a regularly scheduled international passenger service flight under the Convention on International Civil Aviation and the provisions of the Sultanate of Oman Civil Aviation Regulations Part 121 and was on an instrument flight rules (IFR) flight plan. GF-072 was cleared for a VOR/DME approach for Runway 12 at Bahrain. At about one nautical mile from the touch down and at an altitude of about 600 feet, the flight crew requested for a left hand orbit, which was approved by the air traffic control (ATC). Having flown the orbit beyond the extended centre-line on a south-westerly heading, the captain decided to go-around. Observing the manoeuvre, the ATC offered the radar vectors, which the flight crew accepted. GF-072 initiated a go-around, applied take-off/go-around thrust, and crossed the runway on a north-easterly heading with a shallow climb to about 1000 feet. As the aircraft rapidly accelerated, the master warning sounded for flap over-speed. A perceptual study, carried out as part of the investigation, indicated that during the go-around the flight crew probably experienced a form of spatial disorientation, which could have caused the captain to falsely perceive that the aircraft was ‘pitching up’. He responded by making a ‘nose-down’ input, and, as a result, the aircraft commenced to descend. The ground proximity warning system (GPWS) voice alarm sounded: “whoop, whoop pull-up …”. The GPWS warning was repeated every second for nine seconds, until the aircraft impacted the shallow sea. The aircraft was destroyed by impact forces, and all 143 persons on board were killed.

Conclusions

The factors contributing to the above accident were identified as a combination of individual and systemic issues. The individual factors during the approach and final phases of the flight were: non-adherence to standard operating procedures (SOPs) by the captain; the first officer not drawing the attention of the captain to the deviations of the aircraft from the standard flight parameters and profile; the spatial disorientation and information overload experienced by the flight crew; and, the non-effective response by the flight crew to the ground proximity warnings. The systemic factors that could have led to these individual factors were: a lack of a crew resources management (CRM) training programme; inadequacy in some of the airline’s A320 flight crew training programmes; problems in the airline’s flight data analysis system and flight safety department which were not functioning satisfactorily; organisational and management issues within the airline; and safety oversight factors by the regulator. Any one of these systemic factors, by itself, was insufficient to cause a breakdown of the safety system. Such factors may often remain undetected within a system for a considerable period of time. When these latent conditions combine with local events and environmental circumstances, such as individual factors contributed by "front-line" operators or environmental factors, a system failure, such as an accident, may occur.

The investigation showed that no single factor was responsible for the accident to GF-072. The accident was the result of a fatal combination of many contributory factors, both at the individual and systemic levels. All of these factors must be addressed to prevent such an accident happening again.

The airline has taken a number of post-accident safety initiatives to address some of these individual and systemic factors. The airline has reported that it is in the process of enhancing its flight crew training.

Safety Recommendations

The safety issues in this investigation report focus on the above individual and systemic factors. In order to prevent a probability of such occurrence and increase the overall safety of the aviation system, the investigation report has made twelve safety recommendations concerning these issues. They are addressed to: the DGCAM, Sultanate of Oman (seven); the owner-States of Gulf Air (two); Bahrain CAA (one); and International Civil Aviation Organisation (two).

Investigation Procedure

The procedure followed for the conduct of investigation is described in Appendix A.

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1. Factual Information

1.1 History of Flight

On 23 August 2000, about 1930 Bahrain local time,[1] Gulf Air flight 072, (GF-072) an Airbus A320-212, Sultanate of Oman registration A40-EK, crashed in the Arabian Gulf near Muharraq, Bahrain. GF-072 departed from Cairo International Airport, Cairo, Egypt (CAI), with 2 pilots, 6 cabin crew, and 135 passengers on board, for Bahrain International Airport (BAH), Muharraq, Kingdom of Bahrain. GF-072 was operating as a regularly scheduled international passenger service flight under the Convention on International Civil Aviation and the provisions of Sultanate of Oman Civil Aviation Regulations Part 121 and was on an instrument flight rules (IFR) flight plan. The airplane had been cleared to land on Runway 12 at BAH, but crashed at sea about 3 miles north-east of the airport soon after initiating a go-around following the second landing attempt. The airplane was destroyed by impact forces, and all 143 persons on board were killed. Night, visual meteorological conditions existed at the time of the accident.

According to Gulf Air company records and witness statements, the flight crew arrived at the departure gate at CAI about 25 minutes before the scheduled departure time of 1600 (Cairo local time)[2] on 23 August 2000 and the flight was airborne at 1652. According to the cockpit voice recorder (CVR), the captain was performing the pilot-flying (PF) duties, and the first officer was performing the pilot-not-flying (PNF) duties.

About 1921:48, as GF-072 was descending through approximately 14,000 feet above mean sea level (amsl) and about 30 nautical miles (nm) north-west of Bahrain Airport, Dammam Approach gave the following instruction to GF-072:

> Gulf Air zero seven two, uh, self navigation for runway one two is approved. Three point five (3,500 feet)[3] as well approved and Bahrain Approach one two seven eight five (127.85 MHz) approved.

During the readback several seconds later, the captain asked, “Gulf Air zero seven two, confirm we can go for runway one two?” Dammam Approach responded, “Affirmative. Three approves (approvals) you have. Direct for one two (Runway 12). Three point five (3,500 feet) approved. One two seven

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[1] Unless otherwise indicated, all times are Bahrain local time (Universal Co-ordinated Time + 3 hours), based on a 24-hour clock.

[2] Cairo and Bahrain are in the same time zone during the summer.

[3] For clarification, additional information is provided to explain some CVR comments and is shown in parentheses. This information was not recorded on the CVR.

eight five (127.85 MHz) approved." The CVR[4] then recorded the captain instructing the first officer to contact Bahrain Approach. After the first officer made contact, Bahrain Approach stated, "……cleared (for) self position and, uh, as you're cleared by Dhahran. Confirm three thousand five hundred (3,500) feet." The CVR then recorded the captain telling the first officer, "tell them we are cleared to seven thousand (7,000 feet)." The first officer complied and Bahrain Approach responded again to flight GF-072 to continue descent to 3,500 feet[5].

After the flightcrew began executing the approach checklist, Bahrain Approach instructed GF-072 at 1923:21 to continue descent to 1,500 feet and report when established on the VOR/DME[6] for Runway 12. About 1923:36, the CVR recorded the first officer asking, "V bugs?"[7] and the captain responded, "V bugs, one three six (136 knots), two zero six (206 knots), set."

About 1924:38, the CVR recorded the captain saying to the first officer,

> Now you see you have to be ready, for all this, okay? If (it) change on you all of a sudden, you don't say I'll go. You have to know DME. If you can make it or not. Okay?

This was followed by another comment by the captain,

> Now, I've just changed all the flight plan, RAD NAV (Radio Navigation), everything for you, before you even blink. Yeah? Okay ammy?

About 1925:15, with the airplane about 9 nm from Runway 12[8], 1873 feet above ground level (AGL), and an airspeed (computed airspeed recorded by the FDR) of 313 knots, the captain stated, "final descent is seven DME." At 1925:37, with the airplane about 7.7 nm from Runway 12, 1715 feet AGL, and an airspeed of 272 knots, the captain instructed the first officer to "call established". About 1925:45, about 7 nm from the runway, Bahrain Approach cleared GF-072 for the VOR/DME approach to Runway 12 and instructed the flight to contact Bahrain Tower.

About 1926:00, the CVR recorded the captain saying, "final green", and at 1926:04 the first officer contacted Bahrain Tower and stated that GF-072 was "eight DME, established." Tower controller then cleared GF-072 to land and reported wind from 090 degrees at eight knots. The first officer

[4] Appendix B contains the CVR transcript. The transcript expresses the time of CVR comments and sounds in co-ordinated Universal Time (UTC). Bahrain local time/Cairo Summer time is 3 hours ahead of UTC.

[5] FDR data indicate that speed-brakes were used during the descent (from 19:22:49 to 19:24:33, from 19:25:05 to 19:25:57, and then from 19:26:05 to 19:26:13).

[6] VOR/DME stands for Very-high frequency Omni-directional Range/Distance Measuring Equipment and is a navigational aid that provides bearing and distance to the radar facility.

[7] A "V bug" is a movable indicator on the airspeed indicator.

[8] Stated distances from GF-072 to Runway 12 are to the runway's displaced threshold. The runway's displaced threshold is 2.1 nm from VOR/DME facility. Hence, the DME distance is different than the distance to Runway 12.

acknowledged the transmission. About 1926:13, with the airplane about 5.2 nm from the runway, 1678 feet AGL, and an airspeed of 224 knots, the captain called for "flaps one." Seconds later, the captain called for "gear down", and FDR data subsequently showed the landing gear moving to the gear-down position.

About 1926:37, the CVR recorded the captain stating, "Okay, visual with airfield." Seconds later, FDR data showed the autopilot and flight director being disengaged[9]. About 1926:49 and about 2.9 nm from the runway, the airplane descended through 1,000 feet AGL. About 1926:51, with the airplane about 2.8 nm from the runway, 976 feet AGL, and 207 knots, the captain stated, "Have to be established by five hundred feet." Flaps "two" were then selected. As the flight continued on its approach for Runway 12, the captain stated about 1927:06 and again about 1927:13, "….we're not going to make it."

About 1927:23, the captain instructed the first officer to "Tell him to do a three sixty (360 degree) left (orbit)." The first officer complied and the request was approved by Bahrain Tower. The left turn was initiated about 0.9 nm from the runway, 584 feet AGL, and an airspeed of 177 knots. During the airplane's left turn, FDR data showed the flap configuration going from flaps "two" to flaps "three" and then to flaps full. About 1928:17, the captain called for landing checklist. At 1928:28, with the airplane approximately half-way through the left turn, the first officer stated, "landing checklist completed." After about three-fourths of the 360^{o} turn, the airplane rolled out to wings level.

FDR data showed that the airplane's altitude during the left turn ranged from 965 feet to 332 feet AGL, and that the airplane's bank angle reached a maximum of about 36 degrees. About 1928:57, after being cleared again by Bahrain Tower to land on Runway 12, the captain stated, "…we overshot it." FDR data then showed the airplane beginning to turn left again, followed by changes consistent with an increase in engine thrust. About 1929:07, the captain stated, "tell him going around" and FDR data indicated an increase to maximum TOGA[10] engine thrust. Bahrain Tower responded with, "I can see that. Zero seven two sir uh….would you like radar vectors….for final again?" The first officer accepted, and Bahrain Tower instructed the crew to, "fly heading three zero zero (300 degrees), climb (to) two thousand five hundred (2,500) feet." The first officer acknowledged the transmission. During this time, the flaps were moved to position "three" and the gear was selected up. FDR data showed that the gear remained retracted until the end of the recording.

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[9] FDR data indicate that the autothrust remained active throughout the approach, until TOGA was selected.

[10] TOGA stands for Takeoff/Go-Around.

About 1929:41, with the airplane at 1054 feet AGL, at an airspeed of 191 knots, and having just crossed over the runway, the CVR recorded the beginning of a 14-second interval of the aural Master Warning[11] (consistent with a flap-overspeed condition), followed by the statement from the first officer, "speed, overspeed limit…" Approximately two seconds after the beginning of the Master Warning, FDR data indicated a forward movement of the captain's side stick. The captain's side stick was held forward of the neutral position[12] for approximately 11 seconds, with a maximum forward deflection of about 9.7 degrees[13] reached. During this time, the airplane's pitch attitude decreased from about 5 degrees nose-up to about 15.5 degrees nose-down, the recorded vertical acceleration decreased from about +1.0 "G"[14] to about +0.5 G's, and the airspeed increased from about 193 knots to about 234 knots.

About 1929:51, with the airplane descending through 1004 feet AGL at an airspeed of 221 knots, the CVR recorded a single aural warning of "sink rate" from the Ground Proximity Warning System (GPWS), followed by the repetitive GPWS aural warning "whoop whoop, pull up", which continued until the end of the recording.

About 1929:52, the captain requested, "flaps up." About 1929:54, the CVR indicated that the Master Warning ceased for about 1 second, but then began again and lasted about 3 seconds. Approximately 2 seconds after the GPWS warnings began, FDR data indicated movement of the captain's side stick aft of the neutral position, with a maximum aft deflection of approximately 11.7 degrees reached. However, the FDR data showed that this nose-up command was not maintained and that subsequent movements never exceeded 50% of full-aft availability. FDR data indicated no movement from the first officer's side stick throughout the approach and accident sequence.

About 1929:59, the captain requests, "flaps all the way" and the first officer responded, "zero." This was the last comment from the crew recorded on the CVR, which stopped recording at 1930:02. The FDR data showed continuous movement of the flap position toward the zero position after the captain's "flaps up" command. The last flap position recorded on the FDR was about 2 degrees of extension. The last recorded pitch attitude was about 6 degrees nose-down and last recorded airspeed was about 282 knots. FDR data indicated that TOGA selection and corresponding maximum engine thrust remained until the end of the recording.

FDR data indicated that during the go-around after selection of TOGA thrust, GF-072 was initially at about a 9 degree nose-up pitch attitude.

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[11] The aural Master Warning is a continuous repetitive chime.

[12] Forward movement of the sidestick will induce a nose-down pitch response.

[13] Maximum fore and aft sidestick deflection is 16 degrees from the neutral position.

[14] One G is the nominal acceleration of 9.8 m/sec^2.

However, the pitch attitude gradually decreased to about 5 degrees nose-up over the next 25 seconds, where it remained until the captain's forward sidestick commands resulted in nose-down pitch changes.

Figure 1 shows the Instrument Approach Chart for the Bahrain Runway 12 VOR/DME procedure. The VOR/DME radar facility is located approximately 2.1 miles from the threshold for Runway 12. Figure 2 shows an overhead view of the GF-072 trajectory, with selected FDR information, CVR comments and sounds, and air traffic control (ATC) data for the last 4 minutes of flight. Figure 3 shows the side view (vertical profile) for the last 19 seconds of flight.

Figure 1. Instrument Approach Chart for Bahrain Runway 12 VOR/DME Procedure

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

Figure 2. Overhead view of GF-072 trajectory with selected FDR, CVR, and ATC communication excerpts.

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

Figure 3. Side view (vertical profile) of GF-072 trajectory.

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

1.2 Injuries to Persons

Table 1: Injury chart.

	Flight Crew	Cabin Crew	Passengers	Other	Total
Fatal	2	6	135	0	143
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	0	0	0	0	0
Total	**2**	**6**	**135**	**0**	**143**

1.3 Damage to Airplane

The airplane was destroyed by impact forces. The estimated value of the airplane was about US $ 36 million.

1.4 Other Damage

No other damage to property was sustained.

1.5 Personnel Information

1.5.1 The Captain

The captain, age 37, was hired by Gulf Air on 27 December 1979 and employed as an Engineer Cadet. Company records indicated the following additional information:

Promoted to Trainee Engineer:	19 Dec 1983
Promoted to Trainee Flight Engineer, Lockheed L1011:	14 Feb 1988
Promoted to Flight Engineer, Lockheed L1011:	14 Jan 1989
Promoted to Senior Flight Engineer, Lockheed L1011:	14 Jan 1992
Promoted to First Officer, Lockheed L1011:	23 Jan 1994
Transferred to First Officer, Boeing 767:	26 Sep 1994
Promoted to Supervisory First Officer, Boeing 767:	17 Feb 1996
Transferred to Supervisory First Officer, Airbus A320:	25 Feb 1998
Transferred to Supervisory First Officer Boeing 767	6 Jun 1999
Transferred to Supervisory First Officer, Airbus A320:	6 Jan 2000
Promoted to Captain, Airbus A320:	17 Jun 2000

The captain held an Airline Transport Pilot (ATP) certificate (number TA-1178) issued by the Sultanate of Oman, valid until 31 March 2001, with type ratings on the Airbus A320 as Pilot-in-Command (endorsed on 26 April 2000), 767 as Co-pilot, L1011 as Co-pilot. The captain held a First Class Airman Medical certificate issued by the Sultanate of Oman on 3 July 2000, without limitations.

The captain's flight experience according to Gulf Air records was as follows:

Table 2: Flying and Duty Time - Captain

FLYING TIME	HOURS
Total Pilot Time	4,416
Total Pilot in Training sponsored by Gulf Air	186
Total Pilot with Gulf Air	4,230
Total Gulf Air A-320 PIC[15]	86
Total Gulf Air A-320 SIC[16]	997
Total Gulf Air B-767 SIC	2,346
Total Gulf Air L1011 SIC	800

Total Gulf Air Flight Engineer	2,402

The captain's flight and duty time according to Gulf Air records was as follows:

	DUTY TIME (Hrs:Mins)	FLIGHT TIME (Hrs:Mins)
Previous 24 hours	00:00	00:00
Previous 7 days	24:35	17:05
August 2000	61:40	25:35
Since 1 Jan 2000	1,073:17	475:35

The captain's initial (and most recent) proficiency check on the A320 occurred on 26 April 2000 and was valid until 1 November 2000. The captain's initial (and most recent) line check occurred on 16 June 2000 and was valid until 1 July 2001. Prior to 19 August 2000, the two pilots had not flown together as captain and first officer.

Prior to the trip that began on 19 August 2000, the captain last flew on 30 July 2000. He had days off on 31 July and 1 August 2000 and took vacation leave between 2 August and 18 August 2000.

Gulf Air indicated that GPWS training is conducted during Controlled Flight Into Terrain (CFIT) training in recurrent and command training

[15] Pilot-in-Command (Captain)

[16] Second-in-Command (First Officer or Co-pilot)

programs (see paragraph 1.17.1.2.2). The captain’s most recent Training and Proficiency record indicated that he underwent CFIT training during recurrent/upgrade training on 23 April 2000.

Gulf Air records and interviews by investigators revealed the following.

From the captain’s most recent line check that was completed on 16 June 2000, it was indicated that all competency check elements were completed to a satisfactory standard and the designated examiner noted, “well flown test, good SOP operation."

The captain’s initial upgrade checkride that was completed on 26 April 2000 indicated overall “Pass” rating, however, “D” ratings on two emergency manoeuvres, i.e. a rejected take-off and an engine failure after V1. He was not required to “re-sit” on these items. (According to DGCAM’s Designated Examiner Procedures, a “D” rating is the lowest acceptable standard for a sequence, and if more than three unrelated sequences are graded “D”, the overall checkride should be rated as “Fail”).

Gulf Air pilots that had flown with the captain were interviewed and used the following words to describe his personality: responsible, knowledgeable, open to suggestions, happy, very helpful, professional, and sharp. Pilots’ interviewed varied in terms of their description of the captain's confidence in his abilities. One interviewee noted that the captain was confident but not dominant or overconfident. Another interviewee stated that the captain was slightly overconfident but not overpowering or dominant, while another interviewee indicated that the captain was a little loud and confident to the extent that he may have bordered on overconfidence and was somewhat boastful of his knowledge of aircraft systems.

One first officer interviewed recalled an incident involving the captain’s use of the airplane’s engine anti-ice. The captain left the engine anti-ice on after they had flown clear of icing conditions. The first officer challenged the captain on this during flight, but the captain refused to accept the first officer’s explanation and chose to leave the anti-ice on. After landing the first officer showed the captain the reference in the airplane’s manual regarding use of anti-ice; however, the captain refused to accept this interpretation and maintained that his use of engine anti-ice was appropriate. The first officer indicated that during this incident the captain was not happy with his questioning, but never became angry. The same first officer also recalled an incident in which the captain was “strict” with the engineers (maintenance personnel) because an airplane log was not properly signed off regarding one of the Acceptable Deferred Defects (ADDs). The captain would not accept the flight due to this; however, the issue was eventually resolved.

1.5.2 The First Officer

The first officer, age 25, was hired by Gulf Air on 4 July 1999 as a training cadet after attending Gulf Air's Ab-Initio training program.[17] He held a Commercial Pilot (CP) certificate (number CA-558) issued by Sultanate of Oman, valid until 30 November 2004, with type rating on Airbus A320 as co-pilot. The first officer held a First Class Airman Medical certificate issued by Sultanate of Oman on 26 July 2000 without limitations. He was promoted to A320 first officer on 20 April 2000.

The first officer's flight experience according to Gulf Air records was as follows:

Table 3: Flying and Duty Time – First Officer

FLYING TIME	HOURS
Total Pilot Time	608
Total Pilot in Training sponsored by Gulf Air	200
Total Pilot with Gulf Air	408
Total Gulf Air A-320 PIC	0
Total Gulf Air A-320 SIC	408
Total Gulf Air Flight Engineer	0

The first officer's flight and duty time according to Gulf Air records was as follows:

	DUTY TIME (Hrs:Mins)	FLIGHT TIME (Hrs:Mins)
Previous 24 hours	00:00	00:00
Previous 7 days	24:35	17:05
August 2000	123:30	72:03
Since 1 Jan 2000	1,170:43	408:33

The first officer's initial A320 SIC type rating endorsement and SIC proficiency check occurred on 5 November 1999. His most recent A320 proficiency check occurred on 11 June 2000 was valid until 1 January 2001. The first officer's most recent A320 line check occurred on 19 April 2000 and was valid until 1 May 2001.

The first officer's most recent Training and Proficiency record, indicated that he underwent CFIT training during recurrent training on 10 June 2000.

[17] The Ab-Initio training program provides training for cadets (who already hold a commercial pilot license or a frozen airline transport license) to company standards for a line first officer.

Gulf Air records and interviews by investigators reveal the following:

The first officer was sponsored by Gulf Air during his initial training at the Qatari Aeronautical College located in Doha, Qatar. Upon completion of this training, the first officer obtained his Commercial Pilot/Instrument Rated (CPL/IR) license issued by the Sultanate of Oman and was hired by Gulf Air as a training cadet in the Gulf Air Ab-Initio pilot training program.

The first officer failed his initial proficiency check in the A-320 on October 29, 1999. He received marks of “D” on the following: LOC/DME approach, VOR/DME approach, normal landing, crosswind landing, landings from non-precision approach, automation and technology and engine failure procedures[18]. The first officer received additional proficiency training and passed his initial A-320 SIC type rating and proficiency check on November 5, 1999.

After completion of his simulator proficiency check in November 1999, the first officer began his line training on the A-320. The first officer was recommended for his initial flight line competency check on April 17, 2000. On April 19, 2000, the first officer passed his initial line competency check.

One captain that had flown with the first officer, stated that the first officer had difficulty with the approach and departure procedures at Sanaa, Yemen, during a flight on May 11, 2000. This captain indicated that the first officer was able to keep up with the aircraft and perform well at all airports with normal procedures and operations, but had difficulty at Sanaa because he was not familiar with the procedures. The captain felt that the first officer had not been exposed to information specific to Sanaa and did not ask questions regarding the non-standard procedures. The captain noted that neither Gulf Air nor the DGCAM require a special check out for Sanaa airport.

Several Gulf Air captains that had flown with the first officer were interviewed and used the following words to describe the personality of the first officer: timid, meek, mild, polite, disciplined, shy and reserved in social situations, and keen to learn (i.e., inquisitive). While most of the captains interviewed stated that they did not think that the first officer’s reserved nature would hinder him from speaking up during flight operations, others felt that he might have been too reserved to speak up or challenge a captain. One designated examiner/simulator training captain recalled that during a training session, he intentionally exceeded the 30 knot taxi speed limit specified in Gulf Air standard operating procedures (SOPs) and the first officer failed to challenge him regarding this.

[18] According to the DGCAM Designated Examiner Procedures, sequences on proficiency checks are graded on a scale from “A” through “E” where “E” is failing, and if more than three unrelated sequences are graded “D”, the overall checkride should be rated as “Fail”.

1.5.3 Flightcrew 72-Hour History

The captain and first officer were conducting a four-day trip that began at Bahrain on 19 August 2000. The captain and first officer arrived in Cairo, Egypt, at 1350 local time (1050 UTC) on 22 August 2000.

Interviews and records established the following. On the evening of the 22 August, the captain, an air steward (from another set of crew), and a stewardess went to the hotel restaurant about 2030, and remained there until about 2230. The first officer was also at the hotel restaurant about this time, sitting at another table with two stewardesses. The movement of the first officer thereafter could not be accurately determined due to lack of eye-witness accounts and no documentary evidence. The captain went to the hotel casino about 2300. After midnight, the captain, steward, and stewardess took a taxi to Khan Al-Khalil, where they purchased some gifts and had some coffee, before returning to the hotel about 0215. They then went to the crew room for a while and then to the steward's room. About 0315 the captain left them to go to sleep.

The Gulf Air Operations Manual - Vol. 6, Sec 7.2.25, specifies that all A-320 crewmembers away from base are to report for duty one hour before scheduled departure time. Hotel records indicate the following timings (local time) in respect of the GF-072 crew:

1. Call (wake-up) Time 13:40
2. Pick-up Time 14:40
3. Leaving Time 14:40

The driving time from the hotel to the airport is about ten minutes. The flight from Cairo to Bahrain on 23 August 2000 was scheduled to depart Cairo at 1600 local time (1300 UTC). According to the captain who flew A40-EK into Cairo on flight GF-071, the GF-072 flight crew arrived at the gate about 25 minutes before the scheduled departure to take over the airplane. The flightcrew of GF-071 indicated that the captain of GF-072 seemed upset because ground staff had directed them to the wrong gate.

1.5.4 The Air Traffic Controllers

1.5.4.1 Bahrain Approach Control

The air traffic control specialist who was working Bahrain Approach Control during the time of the accident was a trainee who was working under the supervision of an acting air traffic control Watch Supervisor. He had been a trainee in this position since 21 May 2000. Prior to this, he had worked in the Bahrain Air Traffic Control Tower. He began working in the Control Tower in 1991.

The ATC Watch Supervisor has been validated at Bahrain Airport since October 1994. He completed his last Annual Certificate of Competency on 27 March 2000.

The trainee was monitoring GF-072 and approved the flight's request for a 360^o left turn on the initial approach. The trainee stated that airplane's estimated altitude during the orbit was between 500 and 800 feet and that it seemed unusual and tight to him. He indicated that he has seen other 360^o turns, but that they are usually not done so tight or so close to the runway threshold.

The supervisor stated that he observed the radar track of the GF-072 during the approach and that he thought the 360^o turn was very quick and tight. He stated that he had seen other Gulf Air airplanes do 360^o turns during final approach, although it is not common.

1.5.4.2 Air Traffic Control Tower

The Aerodrome Controller has been validated at Bahrain since December 1994 and completed his last Annual Certificate of Competency on 8 March 2000. In addition to being a qualified Local Controller, he was also qualified as a Ground Controller and an Approach Controller.

The Ground Movement Controller has been validated at Bahrain since 1 January 1986 and completed his last Annual Certificate of Competency on 4 June 2000.

The tower controller stated that when GF-072 was handed off to him, he issued a normal landing clearance along with the wind direction and speed. He noticed that GF-072's 360^o turn was very tight. He stated that as the airplane was coming around in the turn, it crossed the final approach course with the nose down and moving very fast. He stated that he had never seen that kind of approach before, and he asked his tower colleague to "look at this." About this time, GF-072 reported that they were going to go around.

1.6 Airplane Information

The accident airplane was an Airbus A320-212, A40-EK, Serial Number 481, owned by the Gulf Air Company (Gulf Air). The airplane was registered and issued an Airworthiness Certificate on September 29, 1994. The aircraft had accumulated 17,370 hours TSN[19] and 13,990 landings at the time of the accident.

[19] TSN = Time Since New

The Gulf Aircraft Maintenance Company (GAMCO) performed all airplane maintenance for Gulf Air. The last maintenance performed on A40-EK was a special maintenance input conducted on 17-18 August 2000. An engine vibration survey and fan trim balance on both engines was performed and no anomalies were noted. There were no Minimum Equipment List (MEL) deferred defects and no significant outstanding Acceptable Deferred Defect or Base Deferred Defects. Certificate of release to return to service was issued on 18 August 2000.

A40-EK was equipped with two CFM International (CFMI)[20] CFM56-5A3 turbofan engines. The number 1 engine (serial number 731-794) was installed on A40-EK on 20 September 1999, and had accumulated 17,901 hours and 14,384 cycles since new. The last shop visit for this engine was a minor repair performed by General Electric (GE) Engine Services at Cardiff, Wales, United Kingdom, in September 1999.

The number 2 engine (serial number 731-795) was installed on A40-EK on 11 May 1998, and had accumulated 18,274 hours and 14,638 cycles since new. The last shop visit for this engine was an overhaul performed by GE Engine Services in April 1998.

The maintenance logs from A40-EK were reviewed for the period from 1 June 2000 to 23 August 2000; two repetitive defects were noted. One involved false engine fire loop indications, and the other writeup noted a brief exhaust gas temperature overheat of the engines after takeoff. Both writeups had been resolved and cleared before the accident flight.

The first officer who flew A40-EK before the accident flight indicated that there was a repetitive AIR PACK 1 OVHT caution during cruise on their flight to Cairo. The flightcrew cleared the fault by switching off the pack. Later in the flight, an AIR PACK 1 REGUL FAULT appeared. The first officer stated that the remainder of the flight was normal and that at no time did there appear to be any problem with the flight controls.

1.6.1 A320 Flight Control Design

The A320 employs a fly-by-wire flight control system. With this design, all flight control surfaces are electrically controlled and hydraulically activated. The horizontal stabiliser and the rudder can also be controlled mechanically. Each pilot uses a sidestick to command pitch and roll changes (instead of a control wheel). These sidestick commands are interpreted by flight control computers, which then send the signals for the appropriate movement of the flight controls.

[20] CFMI is jointly owned by General Electric Aircraft Engines (GEAE) of the United States and Société Nationale d’Etude et de Construction de Moteurs d’Aviation (SNECMA) of France.

The sidesticks are located on each pilot's lateral console; each is spring-loaded to the neutral position. A take-over pushbutton is located on the top of each sidestick. To become the controlling pilot/sidestick, the pushbutton for that sidestick must be pressed and held down. Holding the pushbutton down for over 40 seconds latches the priority on that sidestick and allows that pilot to release his pushbutton without losing priority. The other pilot can deactivate the other pilot's sidestick and assume controlling priority by pressing and holding his take-over pushbutton. The last pushbutton to be engaged determines the controlling sidestick. When only one pilot operates the sidestick, the signals from only his sidestick provide the flight control commands. If the other pilot also operates his sidestick (whether in the same or opposite direction), the signals from both sidesticks are added. When the autopilot is engaged, the first action by depressing the takeover pushbutton is disengagement of the autopilot.

Each side-stick incorporates a spring force to resist movement from its neutral position (i.e., resistance increases as sidestick deflection increases). As shown in Figure 4, resistance increases to 100 Newtons (about 22 pounds) at the sidestick pitch deflection limits of ±16 degrees.

The A320's flight control design (under "normal law")[21] is a load-factor-demand mode with automatic trim throughout the flight envelope. In this mode, flight envelope protections are enabled (see section 1.6.4). In normal law, deflection of the sidestick causes movement of the elevators and/or horizontal stabiliser to maintain load factor proportional to stick deflection and independent of speed. With the sidestick at neutral and wings level, the system maintains +1.0G in pitch (corrected for pitch attitude); there is no need for the pilot to trim when changing speed or configuration. Pitch trim is automatic both in manual mode and when the autopilot is engaged. In turns up to 33^{o} of bank, no pitch corrections are necessary to hold altitude once the turn is established.

At bank attitudes up to 33 degrees, the system holds the commanded bank attitude constant when the sidestick is at neutral. If the sidestick is released at a bank angle greater than 33 degrees, the bank angle automatically reduces to 33 degrees. Sidestick command must be maintained to achieve bank angles above 33 degrees.

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[21] The A320 typically operates under normal mode, but can be operated under alternate and direct modes under certain situations, which offer less automatic protections and may provide different responses to flight control inputs. Recorded FDR data indicate that GF-072 was operating under normal mode.

Figure 4: Side-stick spring force vs. deflection)

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

1.6.2 AutoThrust

Engine thrust on the A320 can be controlled either manually by the flightcrew or automatically by the autothrust (A/THR) system.

When armed, the A/THR system automatically activates if the thrust levers are moved into the "active" range, which is between idle thrust and maximum climb thrust (for 2 engines operative). Outside of this range, thrust levers control thrust directly.

When active, the A/THR system is designed to maintain a target thrust (THRUST mode) or a target airspeed (SPEED/MACH mode).[22] The A/THR system can operate independently or with the autopilot/flight director (AP/FD). When performing independently, A/THR controls the airspeed. If the A/THR system is working with the AP/FD, the A/THR mode and AP/FD pitch modes are linked together.

1.6.3 A320 Cockpit Instrumentation

Figures 5 and 5a: Cockpit Instrumentation

Figure 6: Primary Flight Display (PFD)

The layout of the A320 cockpit includes six display units, control panels, and indication lights to present data to the pilots (see figure 5). The display units are comprised of a primary flight display (PFD) and a navigation display for each pilot, as well as an engine/warning display and a system display located between the pilots' navigation displays. The PFDs provide data such as airspeed, altitude, pitch attitude, bank angle, heading, and flight modes (see figure 6). Display of airspeed is on the speed scale on the left side of PFD and includes the following:

- airspeed: represented by a yellow pointer and reference line
- speed trend: a vertical arrow that starts at the airspeed reference line. The tip of the arrow shows the speed the airplane will reach in 10 seconds if its acceleration remains constant.
- V_{MAX}: the lower end of a red and black strip along the speed scale defines this speed. It is the lowest of the following
    - V_{MO} or the speed corresponding to M_{MO}
    - V_{LE} maximum speed with landing gear extended.
    - V_{FE} maximum speed with flaps extended.

[22] The A/THR system also provides maximum thrust when the airplane's angle of attack exceeds a specific threshold.

Figure 5: A320 Cockpit Instrumentation (Schematic Arrangement)

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

Figure 5a: A320 Cockpit Instrumentation (Actual Instruments)

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

Figure 6: Primary Flight Display

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

Figure 7: Slats/Flaps Configurations

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

1.6.4 A320 Flight Envelope Protections

The A320's flight control design logic provides protection throughout the airplane's flight envelope. These include protections for high speed, pitch attitude, bank attitude, load factor, and high angle-of-attack.

High speed protection is activated at or above $V_{MO}/M_{MO,}$ regardless of autopilot status. As the speed increases above V_{MO}/M_{MO}, the sidestick's nose-down authority is progressively reduced, and a nose-up order is applied to aid recovery. There is no automatic aircraft protection or automatic aircraft response for flap-overspeed.

The nose-down limit under the pitch attitude protection is 15 degrees. This limit is maintained even if further nose-down positions are commanded by the sidestick.

The airplane's load factor is automatically limited to +2.5 G's and –1.0 G when in a clean configuration. For other configurations, the load factor is limited to +2.0 G's to 0 G. Regardless of the pitch commands from the sidestick, the airplane will not exceed these limits.

Stall protection maintains the airplane below its maximum angle-of-attack (α_{max})[23], even if the sidestick is pulled full aft.

1.6.5 A320 Flap Control System

The cockpit flap lever controls the positions of the wing's trailing edge flaps and leading edge slats. The five positions of the flap lever are "0", "1", "2", "3", and "Full" (see Figure 7).

To change the flap setting, the lever must be pulled out of the detent for each position. Gates at positions "1" and "3" prevent the pilot from selecting excessive flap/slat travel with a single action. Flap positions and retraction times between the different configurations are provided in Table 4.

[23] Exceeding the airplane's maximum angle of attack can result in a stall, which is characterised by a loss of lift and loss of altitude.

Table 4: Flap Retraction Time

CONFIGURATION	FLAP POSITION (DEGREES)	FLAP RETRACTION TIME (SEC.)
full to 3	35 to 17[24]	4.6
3 to 2	17 to 15	2.4
3 to 1+F	17 to 10	3.9
2 to 1+F	15 to 10	2.5
1+F to 0	10 to 0	7.4
full to 0	35 to 0	13.2

Take Off & Go-Around Flap Scenario

Flap lever position "1" corresponds to a flap configuration identified as either "1" or "1+F", depending on airspeed. With airspeed greater than 210 knots, the configuration is identified by "1" and corresponds to a slat/flap extension of 18°/0°.) With airspeed less than or equal to 210 knots, the configuration is identified by "1+F" and corresponds to a slat/flap extension of 18°/10°. When in configuration "1+F", if the airspeed increases above 210 knots the flaps will automatically retract to 0°.

1.6.6 Flap Overspeed Situation

In addition to the red and black strip on the airspeed indicator above the flap limit speed, cockpit indications of a flap over-speed situation include a single repetitive chime, illumination of the Master Warning lights, and an ECAM message indicating a flap over-speed situation.

These indications will activate if the airplane exceeds a V_{FE}[25] as follows:

Flap Configuration	V_{FE} (knots)
Full	177
3	185
2	200
1 + F	215
1	230

For the flap configuration that existed at the time the overspeed warning first activated on GF-072, the following ECAM[26] message would have appeared:

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[24] Although flaps "3" correlates to a nominal flap position of 20°, the actual flap extension for this flap setting is 17°.

[25] V_{FE} is the maximum speed for trailing edge flaps extended.

[26] ECAM = Electronic Centralised Aircraft Monitor.

<u>OVERSPEED</u>

-VFE………………………185

The V_{FE} corresponding to the next flap lever position (from the current position and airspeed) is also indicated by an amber “=” along the left side of the PFDs adjacent to the particular airspeed.

1.6.7 Ground Proximity Warning System

The accident airplane was equipped with an Allied Signal Mark V GPWS Warning Computer. The GPWS is designed to generate aural warnings when one of several unsafe modes occurs. The cockpit loudspeakers broadcast the aural warning messages associated with each mode. The CVR from GF-072 recorded the aural warnings associated with Mode 1 (Excessive Rate of Descent), during the last 11 seconds of the recording.[27]

Mode 1 has two thresholds, which are dependent on an airplane’s radio altitude and vertical descent rate. Penetration of the first threshold generates the repetitive warning “SINK RATE”. Penetration of the second boundary generates the repetitive warning “WHOOP WHOOP PULL UP”. Mode 1 warnings are enabled from radio altitudes 2,450 feet to 10 feet.

1.6.8 Weight and Balance

The following information was obtained from the Gulf Air load manifest for GF-072 as well as A320 operating limitations:

Table 5: Weight and Balance

TAKEOFF WEIGHTS		
	POUNDS	**KILOGRAMS**
Basic Operating Weight	97,623	44,281
Ramp Fuel Weight	23,589	10,700
Passenger Weight	18,554	8,416 (61 male, 37 female, 29 children, and 8 infants for a total of 135 passengers)
Baggage Weight	11,325	5,137
Taxi Gross Weight	151,091	68,534
Maximum Taxi Weight	170,635	77,400
Takeoff Fuel Weight	23,149	10,500
Takeoff Gross Weight	150,651	68,334
Maximum Takeoff Gross Weight	169,754	77,000

[27] The Mode 1 alert has priority over other GPWS modes.

TAKEOFF CENTRE-OF-GRAVITY AND SPEEDS	
Takeoff Centre of Gravity (CG)	32.7% mean aerodynamic chord (MAC)
Takeoff CG Limits	15% to 37% MAC
Takeoff Stabiliser Trim Setting	0.9 units airplane nose down (ND)
Takeoff Flap Setting	1 + F
Takeoff Speeds	V_1=154 knots, V_R=161 knots, V_2=161 knots

Based upon the FDR data about the aircraft weights at the time of take-off and landing (impact), the fuel consumed during the flight was about 8,183 kilograms (18,003 pounds). Based on this fuel burn, the cg at the time of the approach would have been approximately 35.9% MAC, which is within the cg limits for the airplane.

ESTIMATED LANDING WEIGHTS		
	POUNDS	KILOGRAMS
Fuel Burn	18,003	8,183
Landing Gross Weight	132,524	60,238
Maximum Landing Gross Weight	142,198	64,500
Landing Speed	V_{APP}=136 knots	

1.7 Meteorological Information

1.7.1 Weather Conditions at Bahrain International Airport

According to the Bahrain Meteorological Office, the reported weather at 1630 UTC (1930 local time) was:

Surface wind direction:	090 degrees True
Surface wind velocity:	08 knots
Visibility/Weather:	CAVOK[28]
Air temperature:	34 degrees Celsius
Dew point:	29 degrees Celsius
QNH:	1001.2 hP (29.57 inches)

Bahrain International Airport ATIS[29] information TANGO on 23 August 2000, at 16:19:30 UTC, was reported as following: "Bahrain information TANGO at 1600. Runway in use 12. Wind 090 degrees 7 knots. CAVOK. Temperature 35. Dew point 29. Q.N.H. 1001. NOSIG. Report information TANGO at first contact." According to ATC transcripts, GF-072 acknowledged having received information TANGO.

The moonrise was 2345 local time and there was no sun or moon in the sky at the time of the accident. Sunset was 1806 local time.

[28] CAVOK stands for "Ceiling and Visibility OK" and indicates visibility of 10 kilometres or more, no clouds exist below the greater of 1500 meters or the highest minimum sector altitude, and no weather of significance to aviation.

[29] ATIS stands for automatic terminal information service.

1.8 Aids to Navigation

1.8.1 Precision Approach Path Indicator (PAPI)

. Runway 12 is equipped with a Precision Approach Path Indicator (PAPI) system (left of runway) calibrated for a 3° visual glide path angle.

The most recent check of the PAPI system for Runway 12 before the accident was conducted by the Bahrain Civil Aviation Affairs on 22 and 23 August 2000, as part of a regularly-scheduled check. The system was found to be serviceable. The PAPI was again checked following the accident on 26 August 2000 and was found to be functioning properly and within prescribed tolerances. There were no adverse reports on the PAPI from any flights on the days before or after the accident.

1.8.2 Radio Navigation and Landing Aids

Table 6: Radio Navigation and Landing Aids

Type of aid CAT of ILS/MLS/ VAR	ID	Frequency	Hours of operation	Site of transmitting antenna coordinates	Elevation of DME transmitting antenna	Remarks
1	2	3	4	5	6	7
VOR/DME (2°E/1996)	BAH	115.300 MHZ	H24	261532.12N 0503915.39E	24FT	121°MAG 0.25 NM MAINT every TUE 0500 – 0800
L[30]	LB	395 MHZ	H24	261530.25N 0503918.62E		121° MAG 0.47NM FM THR RWY 30
LLZ RWY 30 ILS CAT 1	IBI	110.300 MHZ	H24	261656.34N 0503649.44E		301°MAG 2.18NM FM THR RWY 30 MAINT every MON, 0530 – 0800
GP[31] 30	Dots/ Dashes	335.000 MHZ	H24	261555.88N 0503845.47E		3.00°, RDH 55FT
ILS DME		1001 MHZ	H24	261555.88N 0503845.47E	42 FT	Co-located with GP Dist. Zero TDZ RWY 30
MM 30[32]	Dot/ Dash	75 KHZ	H24	261529.77N 0503919.45E		121°MAG 0.48 NM FM THR RWY 30

[30] L = Locator non-directional beacon (NDB)

[31] GP = Glide Path

[32] MM = Middle Marker

1.9 Communications

No communications problems were reported between the crew of GF-072 and any of the ATC facilities. No emergency was declared by GF-072.

1.10 Airport Information

1.10.1 Bahrain International Airport

The Bahrain International Airport is located about 3.3 nm North East of Manama on Muharraq Island at an elevation of 6 feet amsl. The airport is under the control of Bahrain Civil Aviation Affairs. The associated navigational facilities are owned by Bahrain International Airport. The airport has one runway oriented northwest/southeast: Runway 12/30, which is 3956 meters long and 60 meters wide.

The landing threshold of Runway 12 is displaced from the beginning of the runway by 306 meters. That makes the landing distance available (LDA) 3,650 meters for Runway 12. Runway 12 is equipped with high intensity approach lighting system (Category 1), threshold lighting colour wing-bar: green, a high intensity runway lighting system (including runway centre-line lighting with spacing colour white and red, runway edge lighting with spacing colour, and runway end lighting red colour wing-bars). The threshold elevation of Runway 12 is 6 feet amsl and the slope of runway is 0.0 percent. The following figures contain the Airport Charts for Bahrain International Airport:

(a) Figure 8: Aerodrome Ground Movement Chart AD 2-11
(b) Figure 9: Aerodrome Lighting Chart AD 2-13.

Bahrain International Airport was certified as Category 9 aircraft rescue and fire fighting (ARFF) facility. In accordance with this category, the airport is required to maintain a minimum of three ARFF vehicles capable of carrying a total quantity of at least 24,300 Ltrs. of water. The rescue equipment also includes four rescue boats capable of carrying 20 person each, owned by the Coastguard.

Figure 8: Aerodrome Ground Movement Chart AD 2-11

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

Figure 9: Aerodrome Lighting Chart AD 2-13.

To view the above figure, please click its corresponding link under "Figures" on the Home Page.

1.10.2 VOR/DME Runway 12 Approach Procedure at Bahrain International Airport

The Gulf Air instrument approach procedure for VOR/DME Runway 12 at Bahrain International Airport is the same as that specified by the Aeronautical Information Publication (AIP), Bahrain.

The Instrument Approach Chart 13-2 VOR/DME Runway 12 effective 14 November 1997, which is shown in Figure 1, had the following items:

Plan View[33]

Facilities	:	VOR/DME	115.3 (MHz VOR/DME frequency) BAH (Identifier)
		NDB	395 (KHz NDB frequency) LB (identifier)
Outbound	:	322° (magnetic course for Category C & D aircraft) 313° (magnetic course for Category A & B aircraft) D9.0 (outbound fixes)	
Inbound	:	121° (magnetic course) D9.0 (Intermediate Fix) D7.0 } D5.0 } DME fixes D3.0 }	

Profile View

2,500' (amsl altitude over VOR/DME facility Initial Approach Fix)
322° (outbound magnetic course for Category C & D aircraft)
313° (outbound magnetic course for Category A & B aircraft)
1500' (amsl at 9.0 DME/2½ min until end of base turn)
121° (inbound magnetic course)
1,500' (amsl at the Final Approach Fix at 7.0 DME)
870' (amsl at 5.0 DME)
420' (Minimum Descent Altitude for VOR/DME)

Missed Approach: Climb on heading 121° to 2,500' (2,494'), then turn right to rejoin holding, or as directed.

The Instrument Approach Chart also shows location names, crossing altitudes, missed approach procedure, minimum descent altitude(s), etc.

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[33] The plan view is the approach viewed from above; the profile view is the approach viewed from the side.

1.11 Flight Recorders

The flight data recorder and cockpit voice recorder were recovered on 24 August 2000 in the forenoon. The underwater locator beacons installed on each recorder had separated during the impact sequence.

The recorders were transported by a Bahraini Civil Aviation Affairs (CAA) official to the NTSB's laboratory in Washington, DC, USA for initial readouts, and thereafter to BEA's laboratory in Paris, France for further readout analysis.

1.11.1 Flight Data Recorder

The accident airplane was equipped with a Sundstrand FDR, part number 980-4100-AXUN and serial number 10854, which was configured to record over 400 parameters. The FDR had a recording duration of 25 hours before the oldest data were overwritten. Examination of the data indicated that the FDR had operated normally. Certain parameters from the FDR data were included in the CVR transcript (see Appendix "B"). Some parameters of the FDR readout for the last five minutes are attached as Appendix "C".

1.11.2 Cockpit Voice Recorder

The accident airplane was equipped with a Sundstrand (solid-state) 30-minute CVR, part number 980-6020-001 and serial number 0513. The recording consisted of 4 channels that included data from the captain, first officer, and cockpit area microphones. The fourth channel also recorded the interphone and the public address system.

The audio portion began about 15:59:41 UTC and continued uninterrupted until 16:30:02 UTC. The end of the recording was consistent with power interruption at impact. The CVR group, consisting of accredited representatives and technical advisers, collectively reviewed the recording. A transcript of the last 8 minutes and 27 seconds of the recording (from 16:21:35 UTC to 16:30:02 UTC) is attached as Appendix B.

1.11.3 Digital AIDS Recorder

The accident airplane was equipped with another data recording device called a Digital AIDS[34] Recorder (DAR). The DAR provides easy access for downloading data for condition monitoring and trend analysis.

[34] AIDS stands for Aircraft Integrated Data System.

Although the DAR is not “crash-protected” like FDRs and CVRs, the unit from GF-072 was recovered in relatively good condition with only impact marks to the case. However, subsequent examination revealed that no data had been recorded on the tape, and that the tape was found at the beginning of the track.

1.12 Wreckage and Impact Information

The debris field was centered approximately 4 kilometers northeast and on a 030 degree radial from Bahrain International Airport. The wreckage was located in the Arabian Gulf in about 3 meters of water. Estimated surface temperature at sea at the time of the accident was about +33°C. The beginning of the debris field was located near 26°17’51” North/50°38’49” East. The debris field was oriented on a heading of about 030 degrees and was about 700 meters in length. The end of the debris field included portions of the cockpit and lower avionics bay. The width of the debris field varied but was approximately 800 meters at the widest point. The majority of the right and left hand structural pieces were found on their respective sides of the debris field. A broad search of the accident area and the approach to Runway 12 revealed no additional wreckage.

The majority of the airplane was recovered along with all significant airplane structural and flight control surfaces and both engines. No evidence of pre-crash failure and no evidence of fire damage were observed on any of the recovered parts. All examined fracture surfaces were consistent with overload failure.

Damage to circuit breaker panels precluded proper documentation of pre-impact circuit breaker positions or conditions.

The fuselage had fragmented into numerous sections. The wings were sheared from the centre box structure near the same location on both sides. Both engines had separated from the pylons and were heavily fragmented. A large section of the empennage was found in one piece.

Portions of the nose gear and both main landing gear (MLG) assemblies had separated. The right hand MLG retraction actuator was found in the extended position, which corresponds to a "gear retracted" position; the retraction actuator for the left hand MLG was not located.

Most of the horizontal stabiliser was recovered separate from the empennage and was substantially fragmented. The horizontal stabiliser actuator screw was broken with the lowest part remaining connected to the ballnut. The length of the screw from the ballnut corresponded to an estimated 2 degrees nose down attitude. The left side pitch trim control wheel was recovered in good condition; the right side was found fractured and jammed. The pitch trim index showed approximately 1.5 degrees nose down.

Slat position measurements on all the slats showed a 12 degree slat extension. Flap position measurements indicated that the flaps were within 2 degrees of the flap fully retracted position. The flaps/slats control box was recovered with the command handle jammed in position "2" but pulled out of the lock gate. The spoilers control box was recovered in good external condition with the handle found in the retract position and the auto ground spoilers not armed.

Both engines sustained damage consistent with impact and water immersion. Most of the fan blades were found broken just above the root or between the root and mid-span. The remaining portions of the fan blades were bent opposite to the direction of rotation. The engines were found split open in various locations. Examination of the rotating parts within each engine revealed evidence of rotational smearing, rubbing, and blade fractures that were consistent with the engines producing power at the time of impact. Neither engine exhibited any evidence of uncontained failures, case ruptures, or in-flight fires. All of the thrust reverser actuators that were found indicated that the thrust reversers on both engines were in the stowed position.

1.13 Medical and Pathological Information

The remains of the deceased occupants of the aeroplane were examined by the Forensic Science Laboratory (FSL) and Forensic Medicine of the General Directorate of Criminal Investigation, Ministry of the Interior, Bahrain to determine the cause of death. The total number of accident fatalities were (143), and the total number of remains sets examined were (144). One additional remains set was that of a fetus that appeared to have been delivered during the impact. Autopsy examinations and toxicological analysis determined that all the aeroplane occupants died of blunt force trauma. There was no evidence of any thermal injuries or carbon monoxide inhalation. However, traumatic injuries described would have precluded survival after the impact sequence.

Tissue and fluid samples for both pilots were transported to the FAA’s Civil Aeromedical Institute (CAMI) for toxicology analysis. The CAMI laboratory performed its routine analysis for major drugs of abuse and prescription and over-the-counter medication, and the results were negative. The levels of Amphetamine and Methamphetamine were below threshold normally used to state the presence of the drugs, and were therefore reported as negative. The analysis indicated presence of Phenethylamine and Tyramine in the blood and tissue samples of both pilots, however the report noted that these are putrefaction products. Ethanol was detected in the tissue samples taken from the captain and the blood samples taken from the first officer (the CAMI laboratory noted that the ethanol found in these samples may be the result of post-mortem ethanol formation and not from the ingestion of ethanol). No ethanol was detected in the tissue samples taken from the first officer.

The captain indicated that no medication was presently being prescribed to him on his most recent medical examination record on file dated 3 July 2000. The First Officer indicated that no medication was presently being prescribed to him on his most recent medical examination record on file dated 26 July 2000.

1.14 Fire

Examination of the wreckage revealed no evidence of fire damage.

1.15 Survival Aspects

The accident was not survivable.

1.16 Tests and Research

1.16.1 Recovery Study

Although data were obtained during simulation and flight test activities, an additional study of GF-072's final trajectory was performed to determine the effect of certain variables on altitude loss during GPWS recovery. The variables that were examined were 1) the amount of the pilot's pitch-up command; 2) the time between GPWS warning and the pilot's reaction; and 3) the length of time of the pitch command input.

To determine the altitude lost during the recovery, the following scenarios were evaluated assuming the same conditions that existed with GF-072 when the GPWS warning began (altitude, pitch attitude, airspeed, descent rate, etc.). Calculations for the study indicated that the first GPWS alert were consistent with the altitude at which GPWS alerts started on the GF-072 FDR.

Table 7: Responses vs Altitudes Loss

Pitch-up Command	Response Time	Reaction Time	Altitude Loss
full-back stick[35]	1 second	0.25 seconds	300 feet
half-back stick	1 second	0.5 seconds	540 feet
half-back stick	2 seconds	1 second	670 feet

[35] Gulf Air procedures for response to a GPWS warning of "WHOOP WHOOP PULL UP" stipulate that full back stick is to be employed and maintained and that during night conditions, the response should be immediate.

1.16.2 GF-072 Simulation

A series of simulations were organised on 26th and 27th September, 2000 at Airbus Industrie's facilities in Toulouse. An A320 fixed base engineering simulator was used in an attempt to simulate the approach, orbit, and go-around of GF-072 at BAH. The investigation committee was assisted by an Airbus chief test pilot and an Airbus flight test engineer. The simulator sessions also allowed investigative team members to fly the approach to Runway 12 and observe cockpit warnings during the overspeed and GPWS warnings. Several scenarios were flown.

During one of the simulator sessions, the 360º turn and go-around manoeuvres were performed to approximate the flight path and sequence and timing of events recorded on the FDR recovered from A40-EK. However, in these scenarios, the pilots were instructed to recover with full aft stick movement at the onset of the ground proximity warning system (GPWS) "whoop, whoop, pull up" alert. In this scenario, the simulator recovered with about 300 feet of altitude loss.

In the following scenario, a half-back stick command was applied instead of a full back stick command. The delay between the GPWS warning and the stick command was approximately 4 seconds. In this scenario, the simulator recovered with about 650 feet of altitude loss.

In another scenario a recovery was performed by the co-pilot after he verified that the captain took no action to recover from the GPWS "whoop, whoop, pull up" alert. The co-pilot depressed the priority button on his sidestick, announced his control override, and applied full aft side stick input. In this scenario, the simulator recovered with about 400 feet of altitude loss.

In another scenario the 360 degree turn was performed as described above. However, upon selection of TOGA power, the pilots were instructed to make no further control inputs. In this scenario, the simulator trimmed nose down in order to counter the nose up effect due to the thrust increase and to maintain +1.0G, which is the target when the stick is in the neutral position in normal law. The pitch remained positive and the aircraft climbed slowly. This is because the pitch was positive at the beginning of the manoeuvre. In normal law, +1.0G is maintained even in a pitch up attitude if the speed (and thus the vertical speed) is constant.

In the final scenario demonstrated, the 360 degree turn was initiated to match the flight path and sequence and timing of events recorded on the FDR recovered from A40-EK. However, instead of rolling the wings to level upon reaching a heading of about 211 degrees magnetic, the turn was continued at a moderate bank angle at the pilots discretion to align with Runway 12 and the approach and landing were continued. In these demonstrations the pilots were able to successfully land on runway 12 from the 360 degree turn. However, the pilot's noted that the approach was not stabilised and a short amount of time was available to successfully complete the final approach and landing.

While in the simulator, the group examined the reach distance from the left seat to the emergency cancel pushbutton which is located on the ECAM control panel on the central pedestal. The group concurred that the reach distance to the emergency cancel pushbutton was not very far and reaching for it from the left seat was not likely to cause an inadvertent forward side stick deflection.

1.16.3 Flight Tests

On September 27, 2000 a flight demonstration was conducted to observe various conditions similar to the flight profile flown by GF-072 on August 23, 2000. The flight demonstration was conducted during daytime in visual meteorological conditions. The flight test was conducted in an Airbus A320 test aircraft.

The Airbus chief test pilot was the pilot-in-command of the test flight, which was coordinated by an Airbus test flight engineer. Other participants and observers were members from the Technical Investigation Committee including CAA Bahrain, NTSB, BEA representatives as well as Gulf Air, Airbus and FAA technical advisors. The co-pilot was alternatively the chairman of the Technical Investigation Committee and a Gulf Air A320 chief pilot.

Starting from level flight in an clean configuration, manoeuvres were performed to achieve a +0.5G nose down attitude which was held for about 10 seconds. All occupants on the test airplane noted that the +0.5G condition was highly noticeable.

A second test was performed to assess the sensation during the acceleration in climb with a constant 5 degrees nose-up pitch attitude at TOGA power. Non-flying occupants were instructed to close their eyes during the manoeuvre to simulate the absence of visual references. None of the occupants on the airplane reported to have perceived a significant increase of pitch.

Additional tests were performed to simulate the 360 degree orbit of the accident flight, yet continuing to turn at the end of the orbit (instead of rolling out). Several scenarios were flown, with a similar flaps sequence as in GF-072 or with full flaps being selected at the pilot's discretion. The pilots were able to align the airplane with the runway and perform low approaches down to 50 feet where a go-around was performed.

1.16.4 Over-water Light Visibility Study

To determine the surface lighting and overwater visibility conditions that might have existed at the time of the accident, investigation group members observed the area of the crash site several hours after sunset on 2 September 2000. The area was viewed from three different locations: the control tower located on the airport, a point along the shoreline southwest of the approach end of Runway 12, and a jetty southwest of the crash site. As on the night of the accident, there was no visible moon and ceiling and visibility were CAVOK at the times of the observations.

On the day of the study, the observers noted that no lights were visible along the horizon over the water looking to the north or northeast toward the crash site. The observers noted that a few scattered stars were visible in haze from the shoreline and jetty locations. No lights from ships, boats, or buoys were observed on the water from the locations.

1.16.5 Flap Lever Examination

FDR data and flap actuator measurements indicated a flap position of approximately 2 degrees at impact. However, examination of the flap lever after recovery of the wreckage revealed that the flap lever was in position “2” (which would be consistent with a flap position of 15 degrees). The flap lever and the power control unit, including both flap position pick-off units (which provides the FDR flap position data), were sent to the vendor for examination under control of the CAA. Electrical and mechanical tests of the position pick-off units revealed a flap position between one and two degrees.

1.16.6 Final Flight Path Study

A study of the final four minutes of the flight path of GF-072 was conducted to determine what would have been the external visual environment, as viewed from the cockpit, during this part of the accident flight. The co-ordinates of the accident flight path profile derived by the BEA laboratory from the aircraft’s FDR-recordings were used in the study. The study also utilised information from the CVR, and was carried out in two parts:

Part 1: Tests using the Gulf Air A320 flight simulator of at Doha, Qatar. These took place on 17-18 May, 2001.

Two accredited representatives from the Technical Investigation Committee, and the Gulf Air A320 chief pilot, participated in the tests. The co-ordinates of the flight path of GF-072 were programmed into the flight management computer of the simulator. A number of runs simulating the final four minutes of the accident flight were carried out, using both day and night visual displays.

Part 2: Tests at Bahrain International Airport, using a helicopter made available by the Ministry of Interior of Bahrain. These flights took place between 10 and 20 May 2001

The helicopter was flown by an experienced training captain. An accredited representative, and the Chairman of the Recorders Group from the Technical Investigation Committee, participated in the tests. The test flights utilised the coordinates of the flight path of GF-072 to specify precisely the flight profiles flown by the helicopter. The purpose of the helicopter flights was solely to determine, as accurately as possible, the nature of the external visual information that would have been available to the flight crew of GF-072 on the last part of the accident flight.

Video recordings were made during the helicopter flights to facilitate subsequent analysis. The video cameras were positioned at the eye level of pilots. Although the field of view from a helicopter cockpit is greater than that of the A320, the field of view data derived by the BEA laboratory was used to assess the simulated A320 cockpit field of view. The exercises were carried out under dark night conditions, in which the light, visibility, and other environmental conditions were similar to those prevailing at the time of accident. The accident flight profile was also flown in daylight. To enable direct comparison for the purpose of analysis, a composite video presentation was prepared, which simultaneously showed the visual environment from the same aircraft positions in both daylight and night conditions.

The study focused on four segments of the flight path. These segments, and the consolidated observations from the simulator and helicopter flight reconstructions for each one, are outlined below:

Segment 1: A part of the first approach, from 1926:36 to 1927:25:

Observation: The lights of the runway flare path and the ‘strobe lights’ at the touchdown area on either side of the runway 12 would have been clearly visible from the A320 cockpit, and readily identifiable.

Segment 2: A portion of the ‘orbit’, from about 1927:45 to 1928:40:

Observation: There would have been very few external visual reference cues, until the lights of the coast came back into view at about 1928:40.

Segment 3: The last part of the ‘orbit’, where the first officer said to the captain, “Runway in sight … three hundred” at 1928:47:

Observations:

(i) The lights of the runway 12 flare path, and the ‘strobe lights’, would have been visible at about the 10 o’clock position, and would have been clearly identifiable from the cockpit positions of both pilots of

GF-072.

(ii) There was no other feature that would have appeared visually similar to runway 12.

(iii) A comparison of the pattern of lights and visual appearance of runway 12 and the causeway (Shaikh Isa bridge) was done. Given that the causeway is curved, with the presence of moving lights of road traffic and the colouration of such lights, it would have been very difficult to mistake the lights of the causeway for runway 12.

Segment 4: During the go-around, after overflying the runway at the commencement of the 'Master Warning' (1929:41), at which time the aircraft was heading towards the open sea:

Observation: The surface lights on the land mass would have disappeared from view, except for a few very distant lights to the right of the aircraft. At this point, there were no external visual cues ahead of the aircraft, which was heading into 'dark night' conditions of total blackness.

1.17 Organisational and Management Information

1.17.1 Gulf Air

Gulf Air started as the Gulf Aviation Company and was registered as a private shareholding company in Bahrain on 24 March 1950. In 1951, British Overseas Aircraft Corporation (BOAC) became a major shareholder and technical partner in Gulf Aviation. In 1973, the governments of Abu Dhabi, Bahrain, Oman, and Qatar purchased BOAC's shares and bought out the private founder-shareholders. In 1974, the Gulf Aviation Company became Gulf Air, the national carrier of the four states.

The position of president and chief executive (PCE) of Gulf Air is rotated every five years among the four owner countries. From 1 Jan 1996 to 31 Dec 2000, the position of PCE was filled by a nominee from Abu Dhabi. Beginning 1 Jan 2001, the position was filled by a nominee from Bahrain.

At the time of the GF-072 accident, Gulf Air had a fleet of 32 airplanes: 9 Boeing 767-300s, 5 Airbus A-340-300s, 12 Airbus A-320-200s, and 6 Airbus A-330-200s. At the time of the accident, Gulf Air's total number of employees was 5,067. This included 485 pilots: 264 captains and 221 first officers.

Gulf Air Flight Operations is overseen by the President and Chief Executive, who oversees the Vice President Operations. The approved organisational chart indicates that the Vice President Operations is responsible for the Senior Manager Flight Operations, Senior Manager Flight Training, Manager Flight Operations Quality, Senior Manager Flight Operations Support, and Manager Flight Safety.

The DGCAM Principal Operations Inspector (POI) for Gulf Air at the time of the accident indicated that there were numerous management changes involving Gulf Air operations since 1997 (not including fleet training managers or supervisors). The POI indicated that some of the management changes were requested by DGCAM because of its concern about the managers' ability to perform their duties or because of regulatory violations.

1.17.1.1 Gulf Air Flight Safety

Gulf Air pilots can report safety-related incidents to the Flight Safety Department by submitting an Air Safety Report (ASR). A report concerning a "go-around" would be an ASR. Gulf Air indicated that safety concerns may also be reported to the Fleet office by means of a Commander's Voyage Report, which is then forwarded to the Flight Safety Manager. Gulf Air indicated that ASRs received on the A320 fleet vary from 6 to 15 per month. The Flight Safety Manager reviews the reports and may then forward them for further investigation. The investigation report is later forwarded to the appropriate Fleet Office and could be published in the Flight Safety Bulletin. This Bulletin is issued three to four times a year. The Flight Safety Manager indicated that he was in the process of implementing a confidential reporting system for crewmembers at the time of the accident.

The Manager of Flight Safety has been in the Flight Safety Department since 1995. Between 1995 and 1998 he had some assistance, and thereafter, he has been the only person in the Flight Safety Department.

According to several DGCAM memos, Gulf Air did not have the required Accident Prevention and Flight Safety Program at the time of the accident. However, some aspects were in the process of being established. (see 1.17.8)

1.17.2 Gulf Air A320 Flight Crew Training

Gulf Air's flight crew training is conducted in Bahrain and Doha. The training facilities at Bahrain include the Safety and Survival School, and Technical Training Centre. The training facilities at Doha include one A-320 full flight simulator and CBT[36] Centre.

Gulf Air utilised an Ab-Initio pilot training program as a means of training cadet pilots who already held a commercial pilot license (CPL) to the standard required for first officer. There are two means of entry into the Gulf Air Ab-Initio pilot training program: (1) Gulf Air cadets who are graduates of the Gulf Air National Pilot Training Scheme holding a basic commercial pilot's licence with an instrument rating (CPL/IR), or (2) self-sponsored CPL/IR holders with varying levels of experience. According to Gulf Air records, the

[36] CBT = Computer Based Training

last intake of pilot trainees under the Gulf Air National Pilot Training Scheme was Class 96-02, which entered in early 1996. The last trainee who completed the program graduated in April 1998.

A cadet pilot is referred to as a second officer or trainee. Gulf Air's A320 Training Manual stated that the second officers were required to complete multiple simulator exercises and comprehensive line training. The training manual indicated that supervisory first officers are utilised during the early stages of a second officer's training by monitoring the operation and assisting in the training; however, the flight instructor is responsible for the second officer's progress at all times.

1.17.2.1 Recurrent Training and Proficiency Checks

According to the Gulf Air A320 Training Manual, pilots are required to undergo recurrent and proficiency checks in accordance with DGCAM's rules and regulations. The manual indicates that the training is normally accomplished every six months and requires two days. The recurrent training includes a four-hour simulator session designed to refresh the pilot's knowledge and handling abilities, and also includes TCAS and CFIT training.[37]

1.17.2.2 Controlled Flight Into Terrain (CFIT) Training Programme

According to the Gulf Air Operations Training Manual, the CFIT training programme consists of the following:

- "Distribution of CFIT Operators Guide to each pilot; the reference material presented in this covers the history of CFIT, the causal factors involved in CFIT, and recommended procedures for pilots to reduce their risk of being involved in a CFIT accident or incident.

- A video produced by the CFIT Task Force will be required viewing for all pilots during recurrent SEP training at the Safety and Survival School (see Section 1.17.2.5); additionally, the video will be available for viewing in the HQ building, via the Fleet Office.

- All pilots will undergo specific CFIT training in the simulator, as part of their regular recurrent training. This will consist of a once-only CFIT Briefing presented by the Designated Examiner or simulator Instructor, followed by a CFIT Questionnaire to be completed by each pilot. Appropriate recurrent training exercises will be conducted in the simulator".

[37] TCAS stands for Traffic Collision and Avoidance System and CFIT stands for Controlled Flight Into Terrain.

The CFIT Operator's Guide (referred in the beginning of this section) describes the subject in detail, e.g.: Section 3 defines a CFIT accident as "an event where a mechanically normally functioning airplane is inadvertently flown into the ground, water or obstacle". It further highlights the value of the Ground Proximity Warning System (GPWS) in preventing CFIT accidents, and states, "The GPWS warning is normally the flight crew's last opportunity to avoid CFIT. Incidents and accidents have occurred because flight crews have failed to make timely and correct responses to the GPWS warnings". Section 4D describes GPWS warning escape manoeuvres in general and as applicable to each type of aircraft.

Gulf Air Manager Flight Training A-320 provided clarification on CFIT training:

- Once only CFIT briefing is conducted at the time of conversion training.
- Once only CFIT Questionnaire is completed by each pilot during the simulator part of initial CFIT training.
- CFIT simulator exercises are conducted during recurrent training.
- A320 simulator computes ground proximity and rate of descent parameters at all simulated airports. The terrain around Muscat airport provides the most suitable situation for ground proximity simulation.
- A memo dated 20 April 2000 issued to Designated Examiners/Simulator Instructors on Base Check reminder states, "each pilot should complete TCAS, CFIT and Windshear exercises…".
- The content of the CFIT simulator training is left to the discretion of the instructor; CFIT is a box to be ticked on the training records in case of recurrent training; there was no detailed syllabus for CFIT training.

The Airbus Industrie's A320 Normal Course Syllabus for pilots Part 142 includes "GPWS Pull-up Demonstration". Gulf Air Manager Flight Training A320 indicated that there was no similar syllabus for Gulf Air, and no requirement to execute such a demonstration for the A320 fleet.

1.17.2.3 Flap Over-speed Situations

Gulf Air indicated that it has no training for flap overspeed situations. Information on configuration changes is provided in the Gulf Air A320 Flight Crew Operating Manual (FCOM). (See Section 1.17.3.6).

1.17.2.4 Go-around

Gulf Air indicated that training for single-engine go-around procedures is conducted during initial, up-grade and recurrent training. Training for two-engine go-around procedures is conducted during initial and up-grade training.

1.17.2.5 Safety Equipment Procedures (SEP) Training

Gulf Air conducts the SEP training at its Safety and Survival School in Bahrain. Gulf Air Operations Manual Training describes the scope of emergency training for each aircraft type, model and configuration in which the crewmembers are to fly, as appropriate to that crewmember's station.

1.17.3 Gulf Air A320 Procedures

1.17.3.1 Speed Restrictions during Descent

There is no specific speed restriction below 10,000 feet within the airspace (applicable to the flight path of the accident aircraft) under the control of Dammam, Saudi Arabia or Bahrain.

Gulf Air procedures for descent and approach specify: "A speed limit of 250 knots below 10,000 feet is the defaulted speed, in the managed speed descent profile. The flight crew may delete or modify it if necessary…". The aircraft are expected to check with the ATC if there are any speed restrictions before selecting speeds higher than 250 knots when below 10,000 feet.

According to Gulf Air SOPs the instrument approaches are to be made on the "managed speed modes".

1.17.3.2 Stabilised Approach

The A320 FCOM describes the requirements of stabilised approach as follows:

(a) Non-precision approach (Approach Speed Technique):

"The standard speed technique is to make a stabilised approach using AP/FD and A/THR. The aircraft intercepts the final descent path in the landing configuration and at VAPP. For this purpose, the flight crew should insert VAPP as a speed constraint at the FAF. In all cases, the crew should use managed speed. At 1000 feet above runway elevation it should be stabilised on the final descent path in the landing configuration with thrust above idle."

(b) Visual Approach:

"Perform the approach on a nominal 3 degree glide slope using visual references. Approach to be stabilised by 500 feet AGL on the correct approach path, in the landing configuration at VAPP."

(c) If the aircraft is not stabilised:

> "Flight crew should consider making a go-around if the aircraft is not stabilised on the approach path in landing configuration at 1000 feet (in instrument conditions) or at 500 feet (in visual conditions), (or as restricted by airline policy/regulations)."

Gulf Air Operations Information Bulletin No. 05/2000 issued on 28 March 2000 states:

> "All approaches shall be stabilised by 1000 feet Height Above Touchdown (HAT) in Instrument Meteorological Conditions (IMC) and by 500 feet HAT in Visual Meteorological Conditions (VMC)."

1.17.3.3 Circling

Gulf Air procedures for a circling approach state that the minimum circling height is the greater of:

- the minimum specified under "Circle-to-land" on the Jeppesen approach chart; or
- the Company circling minimum of : 1000 ft. AAL[38]

The minimum circling height according to the Jeppesen approach chart was 600 feet.

1.17.3.4 Go-Around

The Standard Operating Procedures section of the Gulf Air A320 FCOM contains go-around procedures for both with and without flight director guidance.

For a go-around without flight director, the procedure calls for the following actions (with the first three actions to be applied simultaneously):

THRUST LEVERS…………………………...TOGA
ANNOUNCE…………………………………"GO AROUND – FLAPS"
ROTATION……………………………………15^o OF PITCH
Rotate to 12.5^o if one engine is out.
FLAPS…………………………………………RETRACT ONE STEP
Announce "FLAPS" when indicated.
ANNOUNCE…………………………………..."POSITIVE CLIMB"
ORDER……………………………………….."GEAR UP"

[38] AAL = Above Aerodrome Level

L/G UP……………………………………….SELECT
CONFIRM/ANNOUNCE………………………"GEAR UP – FLAPS"

For a go-around *with* flight director, the same procedures as listed above are stipulated, except for the following procedure for pitch:

ROTATION…………………………………PERFORM
- Rotate the aircraft to get a positive rate of climb and establish the required pitch attitude as directed by the SRS[39] *pitch command bar.*
- Check and announce the FMA: TOGA (or MAN TOGA), SRS, GA TRK
- Go-around without Flight Director – continued procedure.

- <u>At GA thrust reduction altitude:</u>
  Disregard CLB or LRV CLB flashing on FMA[40].

- <u>At go around acceleration attitude:</u>
  (The acceleration altitude at Bahrain is 1,500 feet AAL)
  For go around with no FD, thrust reduction and acceleration altitude should be the same.

  - Select speed target to green dot.
  - Adjust aircraft attitude to 10/12 degrees.
  - Select thrust levers to CL detent and activate the A/THR.
  - Set FD to ON. (Basic mode HDG V/S or TRK FPA engages).
  - Select appropriate mode.
  - Check FMA.
  - Retract the flaps at appropriate speeds (see Flap Retraction Schedule).
  - Monitor go around routing and first cleared altitude.

Note: If thrust levers are set to CL detent at thrust altitude, a thrust reduction may occur if the current speed is above the speed target.

1.17.3.5 Flap Retraction Schedule

The flap retraction schedule (F[41],S[42] and Green Dot Speeds) are computed by the FMGC based on current aircraft weight. During the go-around procedure, the selection of TOGA power automatically transfers this data to the captain and First Officer's speed tape on their PFD. This is

[39] SRS = Speed Reference System
[40] Disregard climb or lever climb flashing on Flight Mode Annunciator.
[41] F = Minimum speed at which the flaps may be retracted at takeoff/go-around.
[42] S = Minimum speed at which the slats may be retracted at takeoff/go-around

displayed as ‘F’, ‘S’ and Green Dot (o)[43] on the speed tape. This data is also displayed on the ‘PERF’[44] page of the MCDU[45].

When flaps/slats are in configuration 3 or 2, the minimum flap retraction speed (as described above) is displayed in green along the speed scale on the captain’s and first officer’s PFD.

1.17.3.6 Over-speed Situations

The Abnormal and Emergency section of the Gulf Air A320 Flight Crew Operating Manual (FCOM) provides V_{MO} and V_{FE} airspeeds. The Supplementary Techniques section of the FCOM provides pilot procedures and airplane response as airspeeds approach or exceed V_{MO}. No procedures are included in the Gulf Air or Airbus A320 FCOMs for flap overspeed situations (see Section 1.17.2.3).

1.17.3.7 GPWS Alert

The Abnormal and Emergency section of the Gulf Air A320 FCOM contains procedures for response to GPWS alerts. For night or instrument meteorological conditions, the procedure states that flight crews are to “apply the procedure immediately; do not delay reaction for diagnosis.” When WHOOP WHOOP PULL UP OR TERRAIN WHOOP WHOOP PULL UP sounds, the procedure calls for simultaneously doing the following:

AUTOPILOT…………………….OFF
PITCH ……………………….PULL UP (*Pull up to full back stick and maintain*)
THRUST LEVERS……………..TOGA

The FCOM states that GPWS response procedures are “memory items” that are to be applied without referring to manuals or checklists.

1.17.4 Flight Crew Decision-making and Task Sharing

The “Abnormal and Emergency” section of Gulf Air’s A320 FCOM specifies task sharing between the two pilots that applies to all procedures. The pilot flying (PF) is to remain flying throughout the procedure, and is responsible for

- thrust levers,
- control of flight path and airspeed,
- aircraft configuration (request configuration change),

[43] Green Dot (o) = Engine out operation speed in clean configuration – best lift to drag ratio speed, corresponds to the final take-off speed.

[44] PERF = Performance

[45] MCDU = Multi Control Display Unit

- navigation, and
- communication[46]

The pilot not-flying is responsible for

- reading aloud the ECAM and checklists and
- executing required actions or actions requested by the PF

1.17.4.1 Standard Calls

The A320 FCOM describes the standard calls in respect of the Flight Parameters as follows:

> "PNF will make call-outs for the following conditions during final approach. Attitude callouts also to be made through to landing.
>
> - "SPEED" when speed becomes less than Vapp – 5 or more than speed target +10.
> - "SINK RATE" when V/S is greater than 1000 ft/min.
> - "BANK" when bank angle becomes greater than 7 degrees.
> - "PITCH" when pitch attitude becomes lower than –2.5 degrees or higher than +10 degrees.
> - "LOC" or "GLIDE" when either localiser or glide slope deviation is one dot.
> - "COURSE" when greater than 1/2 dot (VOR) or 5 degrees (ADF).
> - "___ FT HIGH (LOW)" at altitude check points."

1.17.4.2 Crew Resource Management Program

Under the Sultanate of Oman Civil Aviation Regulations (CARs), Gulf Air has had a requirement for a crew resource management (CRM) program since June 1999.

The Acting Manager for Human Factors for Gulf Air assumed his duties in December 1999. Included in his duties is establishment and management of a CRM program for Gulf Air. He described the CRM training initiative at that time as "non-existent". He stated that Gulf Air had an informal CRM program from about 1992 until late 1996 or early 1997 that was developed in-house. It was not used thereafter. He suggested that the previous Manager

[46] Under the "Normal" section of the FCOM, the PNF is responsible for communication.

of Human Factors resigned because of continued frustration trying to get the CRM program organised and authorised.

According to the Acting Manager for Human Factors, a company was selected in January 2000 to develop a CRM program. Original plans were to initiate facilitator training in February and March 2000 and line pilot initial training in May 2000. However, contract negotiations have delayed the effort. According to Gulf Air, initial CRM courses for its pilots commenced on 1 November 2000. The manager indicated that cultural aspects of the region would be addressed in the CRM training.

1.17.5 Crew Pairing

Flight crew who have recently converted to the aircraft type, or have recently been upgraded to Commander, will be restricted to which crew members they may operate with and their roster will be marked with a blue line. The blue line period extended from the initial line check until a minimum of 40 sectors have been completed in the respective crew category, on Gulf Air operations. This was changed to “20 Sectors (for newly promoted Commanders) and 10 Sectors (for pilots transferring from another fleet)” from 15 August 1999. Gulf Air indicated that this was in accordance with the minimum requirements specified in the regulations.

1.17.6 Gulf Air Accident and Incident History

On 23rd September 1983, a Gulf Air Boeing 737 was destroyed as the result of an in-flight detonation of an explosive or incendiary device near the airplane’s forward cargo door. Fire and Smoke produced from the explosion entered the control cabin and passenger compartment and resulted in the incapacitation of the flight crew to the extent that control of the airplane became impossible. The aeroplane was destroyed on impact and all of the 112 persons on board were killed.

In March 1997, a Gulf Air A320 was involved in an accident in which the airplane deviated off the right side of Runway 31 at Abu Dhabi during takeoff. Although there were no fatalities, 3 of the 107 passengers and 1 of the 8 crewmembers sustained serious injuries and the airplane suffered major damage. Gulf Air did not provide details of the accident investigation findings to its A320 pilots.

On 18 August 1999, a Gulf Air A320 (A40-EN) was involved in a hail-storm incident. After departure from Dubai, during climb to the cleared altitude of FL190, the aircraft encountered hail storm and both windscreens shattered. The aircraft diverted to Abu Dhabi and executed an autoland. Both crew confirmed weather returns from the radar were green on their track, and no significant weather was ever reported to the crew. Despite a request from DGCAM early on the morning of 19 August 1999, the CVR was not secured, and the recording information was subsequently lost.

On 27 January 2000, Gulf Air flight A320 (A40-EI), on a flight GF-973 from Abu Dhabi to Amman, experienced a depressurisation incident. The first officer from GF-072 was then the second officer on flight GF-973 (receiving line training in the right hand seat) and was being evaluated by a supervisory first officer, who was seated in the observer's seat. The aircraft apparently struck debris during takeoff from Abu Dhabi and received damage that prevented proper pressurisation on climb-out. A Gulf Air board of inquiry into the incident cited the crew's "poor airmanship and awareness" as a factor contributing to the incident. The board was critical of the crew, particularly the captain and the first officer (of GF-973). However, as a result of the incident, the then second officer of GF-973 (i.e. the first officer of GF-072) was ordered to complete two days of CBT systems training, and four hours of simulator training to "help improve cockpit awareness, task sharing, ECAM handling and decision making."

GPWS incidents on 3 January 2000 and 22 January 2000 were on A340 aircraft. Initial GPWS activation incident was related to pilot's deviation from approach profile, pilot misunderstanding of briefing material, and false warning.

1.17.7 Gulf Air Violations/Sanctions/Misc

A review of about three years preceding the accident indicates that there have been a number of violations/cases of non-compliance with the DGCAM regulations in areas such as:

- Flight operations
- Cabin safety
- Flight and duty time and rest period limitations
- Minimum Equipment List(s)
- Emergency equipment
- Flight training
- Record keeping
- Unapproved changes to various programmes

Examples of sanctions

- Revocation of ETOPs time.
- Revocation of three-engine ferry flight.
- Crew licence suspensions

1.17.8 Oversight of Gulf Air

The regulatory oversight of Gulf Air is the responsibility of the Directorate General of Civil Aviation and Meteorology (DGCAM). The DGCAM is organised under the Ministry of Communications for the Sultanate of Oman. The DGCAM is also responsible for analysing accidents and incidents involving Gulf Air.

The DGCAM Principal Operations Inspector (POI) for Gulf Air at the time of the accident worked as an inspector and manager for Transport Canada for 19 years before coming to Bahrain in 1997. He has been rated on the A310, A320, A330, and A340. When the POI initially began his assignment, he monitored the pilot training programs as a part of planned surveillance. He stated that he also participated in airworthiness issues involving Gulf Air. In October 2000, he resigned his assignment and has since returned to Canada.

The DGCAM had approved a 3-year implementation program for Gulf Air to adopt CAR 121 requirements with a target date of December 2000. The grace period was designed to allow Gulf Air sufficient time to develop new procedures and amend existing manuals. Some of the issues on this subject are still being addressed.

ICAO has scheduled a Safety Oversight Audit at Oman in April 2001 under the Universal Safety Oversight Programme.

1.17.8.1 DGCAM Oman Safety Oversight

A review of correspondence between DGCAM and Gulf Air revealed numerous letters citing lack of compliance with CARs. The records in respect of some letters requiring/requesting action indicate the following:

(a) the company could not locate response(s) having been returned to the DGCAM, nor were there records of these requested actions having been addressed by the company;

(b) letters were actioned internally by the company in some way, but no reply to the DGCAM could be located;

(c) action was taken on certain issues, however, it was deemed unacceptable corrective action by DGCAM and to be re-addressed by the company; some such items involved lengthy time frames in correspondence;

The POI at that time, stated that Gulf Air did not meet nor have a number of regulatory required programmes; such as:

- CRM
- quality management
- safety awareness
- surface contamination complete with required crew training,
- crew records for flight duty and rest time limitation.

A number of issues raised by the POI are still in the process of resolution.

The records indicate the following:

- the DGCAM raised a number of regulatory and operational concerns to the Board of Directors of Gulf Air;

- the Board appointed a technical committee comprising of the DGCAs of owner States to advise on the remedial actions in September 1999; and

- the Board agreed on the technical committee recommendations that stipulated a "total co-operation between the DGCAM and Gulf Air management to achieve/maintain a high level of safety" in December 1999.

1.17.9 ICAO Special Evaluation

In response to a request by the DGCAM, a consultant from the International Civil Aviation Organisation (ICAO) conducted a special evaluation to review the level of Gulf Air's compliance with Civil Aviation Regulations. The special evaluation was done from 17 October through 21 October 1998. During this period, DGCAM personnel and Gulf Air Flight Operations managers were interviewed and an A320 cockpit enroute check was conducted. Numerous correspondence documents as well as circumstances of recent incidents regarding non-compliance of regulatory requirements were reviewed. The following are two of the conclusions from the above review:

- delayed or non-compliance with regulatory requirements,

- Gulf Air's opposition to CAR 121.

Based on this review the ICAO letter to DGCAM dated 25 October 1998 stated that, except for isolated incidents, most infractions could be traced to inadequate supervisory oversight rather than deliberate disregard for the regulations. However, the regulatory compliance level by Gulf Air Flight Operations was assessed as satisfactory.

1.17.10 Lufthansa Consulting Group's Assistance

The Board of Directors for Gulf Air decided on 7 December 1999 to employ the services of a consultant to assist in upgrading the Gulf Air operating guidance and documentation. After reviewing several proposals, the Board agreed to appoint Lufthansa Consulting Group for this purpose. The Lufthansa Consulting Group was appointed in June 2000.

1.17.11 Gulf Air Post-accident Safety Initiatives

1.17.11.1 Go-Around Procedures

On 7 November 2000, Gulf Air's Acting Manager Fleet Training A320 has issued a memo to all A320 training captains regarding go-around procedures. The memo directed that all pilots are to practice two-engine go-around procedures during Simulator Continuation Training and under the following conditions:

1. Flight Directors 'ON'
2. Flight Directors 'OFF'
3. Track/FPA[47] selected
4. Go-around ATC clearances other than standard published go-around procedures.

Note : Ab-initio and Upgrade Training syllabi include single and two-engine go-around training. However, the Continuation Training Syllabus included single engine go-around training, but not two-engine go-around training. This memo was issued to enhance the Continuation Training Programme.

1.17.11.2 Ab-Initio Training

Following the accident, Gulf Air suspended additional hires of ab-initio pilots until further notice. Gulf Air also suspended its Ab-Initio Simulator Training program, pending a full review, in order to assess it against industry standards and recent changes to regulatory requirements. Gulf Air indicated that these actions were prompted by issues arising from the GF-072 accident and by a recent DGCAM Oman Operational Directive specifying new requirements for simulator training. According to Gulf Air, the intent of the directive is to increase the proportion of simulator training that is conducted with a normal crew complement (i.e., a captain in the left seat and a first officer in the right seat), rather than pilot trainees being paired with another trainee of the same level. Gulf Air indicated that the directive is also intended to ensure that a trainee undergoes a greater share of training in his proper seat and a more realistic operating crew environment.

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[47] When selected, Track/Flight Path Angle mode provides a display of the airplane's track and its flight path vector on the primary flight display.

1.17.11.3 Cockpit Crew Resource Management (CRM) Training

Gulf Air indicated that the initial CRM Training course was already under development at the time of the GF-072 accident. Initial CRM courses for Gulf Air pilots commenced on 1 November 2000. Gulf Air's intention is to complete the Initial CRM training for all Gulf Air pilots no later than June 2001.

1.17.11.4 Command Upgrade Training

Gulf Air modified its Command Line Training program to include an additional final phase of 20 sectors (minimum) with a "normal" crew complement consisting of the upgrade trainee in the left seat, an instructor or examiner in the jump seat, and a line first officer in the right seat. Gulf Air indicated that this training process is intended to allow an assessment of the trainee commander's ability to operate satisfactorily with a first officer during actual line operations, with the benefit of the guidance and support available from the instructor. DGCAM Oman has approved these modifications to the training program.

1.17.11.5 Gulf Air A320 Fleet Instructions

Gulf Air has issued A320 Fleet Instructions on the following subjects (attached as Appendix D):

(a) ***Standard Operating Procedures (SOP)**,* A320 Fleet Instruction No. 14/2000 (Re-issue No. 1) dated 4 October 2000:

(1) Speed Control Below FL100 or 10,000ft. amsl.

(2) Stabilised Approach Criteria

(3) Visual Manoeuvring in the Vicinity of an Airport

The Fleet Instruction assures the pilots as follows:
"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."

(b) ***Flight Director Usage During Non-precision Approach,***
A320 Fleet Instruction No. 18/2000 dated 4 February 2001.

1.17.11.6 Recurrent Training and Checking

Gulf Air is implementing enhanced training on go-around procedures for all A320 pilots during their recurrent training sessions. Gulf Air indicated that the training is intended to: 1) cover new company requirements involving speed control, stabilised approaches, and visual manoeuvring that were published in the Fleet Instructions Numbers 14/2000 and 18/2000 (refer to Section 1.17.11.5 and Appendix D); and 2) practice go-around procedures with both engines operating under the following circumstances:

- Flight directors on and off;
- Track/FPA (Flight Path Angle) selected;
- Go-arounds conducted in accordance with ATC clearances that differ from published procedures.

1.17.11.7 Instructor Selection and Training

Gulf Air suspended all instructor appointments on 28 September 2000 in order to allow a review and enhance the instructor selection criteria and procedures in order to comply with the DGCAM operations directive[48].

1.17.11.8 Pilot Selection

All first officers eligible for upgrade will be required to undergo screening tests to assess their suitability for command, including screening tests conducted by an accredited aviation psychology organisation. All ab-initio second officers and direct-entry pilots undergo screening tests conducted by an accredited aviation psychology organisation.

1.17.11.9 Modification to A320 Automatic Flight System (AFS) Automatic Return of Flight Director (FD) Bars at Go-Around Initiation

Gulf Air is in the process of implementing an Airbus Industrie modification to the A320 Automatic Flight System. This modification will automatically re-instate the FD bars at go-around initiation. The FD bars will automatically display SRS instructions, and level wings on the track at the time of initiating "Go-Around", and will return in 'HDG/v/s' mode.

1.18 Additional Information

1.18.1 Spatial Disorientation Study

The above study was undertaken at the US Naval Aerospace Medical Research Laboratory, Pensacola, Florida, USA. The scope of the study addressed the lateral and vertical acceleration and estimated perceived pitch aspects. The perceived pitch experienced by occupants of the airplane was estimated from a computation based on the net gravitational force.

[48] The draft Operations Directive was initiated to all operators on 5 June 2000 for consultation purposes. The final Operations Directive was issued on 18 September 2000.

1.18.2 Flight Safety Foundation Study of Controlled Flight Into Terrain (CFIT) Accidents

In the early 1990s, the Flight Safety Foundation (FSF) created a CFIT Awareness Task Force to promote general CFIT awareness, which evolved into an international Approach and Landing Accident (ALA) Reduction Task Force.

Several factors that frequently appeared in CFIT accident reports included night and limited visibility conditions, terrain not observed until just before impact, loss of horizontal or vertical situational awareness, unfamiliarity with terrain and obstructions, flight crew uncertainty about altitudes and distance from the airport, navigational equipment improperly set or misinterpreted by the flight crew, and an unstabilised approach.

The FSF, using statistics from the UK CAA global database, found that 287 of the 621 fatal CFIT accidents world-wide between 1980 and 1986 occurred during the approach and landing phase of flight. A study commissioned by UK CAA for FSF[49] determined the 5 most frequently identified primary causal factors as follows:

1. Omission of action/inappropriate action - generally referred to the crew continuing descent below the specified minimum without visual reference or when visual cues were lost .
2. Lack of positional awareness in the air - generally involved a lack of appreciation of the aircraft's proximity to high ground.
3. Flight handling.
4. "Press-on-itis,". It is referred to a flight crew's "determination to get a destination or persistence in a situation when that action is unwise."
5. Poor professional judgement/airmanship.

The study also determined that all five primary causal factors involved crewmembers. On the basis of the results of this study, the FSF Approach and Landing Accident (ALA) Reduction Task Force issued nine conclusions and recommended several initiatives to support each conclusion[50].

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[49] "A Study of Fatal Approach-and-Landing Accidents Worldwide, 1980-1996," Flight Safety Digest, February-March 1998. This study was also included as part of a special FSF report, "Killers in Aviation: FSF Task Force Presents Facts About Approach-and-Landing and Controlled-Flight-Into-Terrain Accidents," Flight Safety Digest, November-December 1998 and January-February 1999.

[50] These conclusions and recommendations were presented at the FSF's Corporate Aviation Safety Seminar, held from 5 to 7 May 1998.

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

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[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 nm	Time LT	Height AGL ft	CAS knots	Flaps 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 [missed approach point]	1927:23				The captain asks the first officer "Tell him (ATC) to do (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.

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[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).

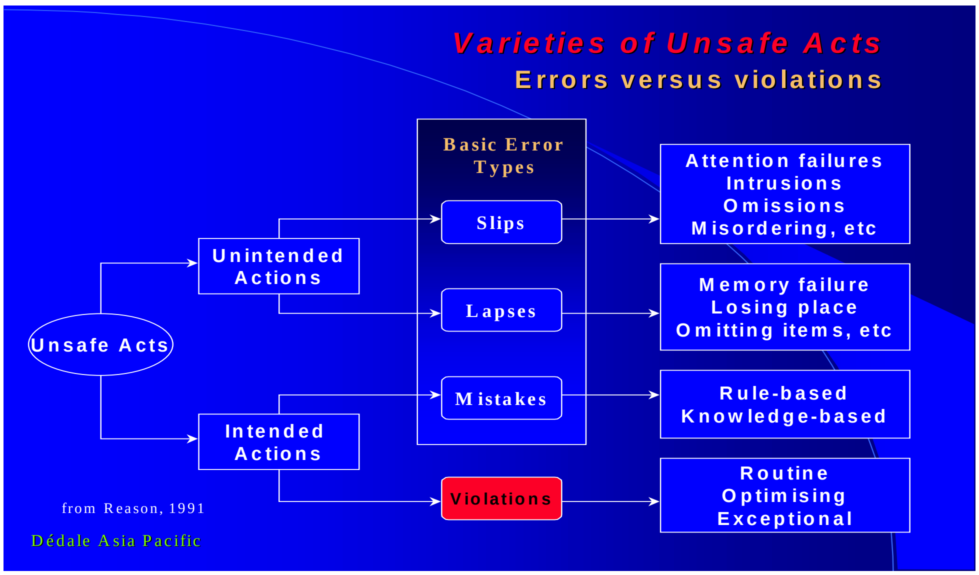

Figure 10: Varieties of Unsafe Acts

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:

Recommendation A-81-019: 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.

Recommendation A-81-020: 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.

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3. Conclusions

3.1 Findings

1) The captain did not adhere to a number of SOPs, particularly during the approach and final phases of flight:

    (a) During the descent and the first approach, flight GF-072 had significantly higher speed than standard.

    (b) During the first approach, standard ‘approach configurations’ were not achieved, and the approach was not stabilised on the correct approach path by 500 ft.

    (c) When the captain perceived the he was ‘not going to make it’ on the first approach, standard go-around and missed approach procedures were not initiated.

    (d) Instead, the captain executed a 360-degree orbit, a non-standard manoeuvre close to the runway at low altitude, with a considerable variation in altitude, bank angle and ‘g’ force.

    (e) A ‘rotation to 15 degree pitch-up’ was not carried out during the go-around after the orbit.

    (f) Neither the captain nor the first officer responded to hard GPWS warnings.

    (g) In the approach and final phases of flight, there were a number of deviations of the aircraft from the standard flight parameters.

2) 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 the captain to them, as required by SOP’s.

3) During the go-around after the orbit, it appears that the flight crew experienced spatial disorientation:

    (a) During the go-around the aircraft was accelerating rapidly, as the captain was dealing with the flap over-speed situation, he applied a nose-down side-stick input that was held for about 11 seconds, resulting in a nose-down pitch of 15 degrees.

    (b) A perceptual study conducted using FDR recordings of the accident flight indicated that while the aircraft was accelerating with TOGA power in total darkness, the somatogravic illusion could have caused the captain to perceive (falsely) that the aircraft was ‘pitching up’. He would have responded by making a 'nose down' input. As a result the aircraft descended and thereafter flew into the shallow sea.

4) Controlled Flight Into Terrain:

(a) The GPWS 'sink rate' alert sounded, followed by the ground proximity warning 'whoop, whoop, pull up' which sounded every second for nine seconds until the impact.

(b) The analysis of FDR and CVR recordings indicated that neither the captain nor the first officer perceived, or effectively responded to, the threat of the aircraft's increasing proximity to the ground in spite of repeated hard GPWS warnings, and continued addressing the comparatively low priority flap over-speed situation.

(c) The captain did not fully utilise critical information provided by the aircraft instruments during the final phases of the flight, where he was also experiencing 'information overload'.

5) During the approach and final phases of the flight, the captain did not consult the first officer in the decision making process, and did not effectively use this (the first officer) valuable human resource available to him. A lack of training in CRM contributed in the flight crew not performing as an effective team conducting the operation of an aircraft.

6) Gulf Air's Organisational Factors:

(a) Inadequacy was identified in Gulf Air's A320 training programmes such as adherence to SOPs, CFIT, and GPWS responses.

(b) At the time of accident, Gulf Air's flight data analysis system was not functioning satisfactorily, and the flight safety department had a number of deficiencies, which restricted the airline's awareness in many critical safety areas.

7) Safety Oversight Factors:
A review of about three years preceding the accident indicated the following:

(a) The regulatory authority (DGCAM) had identified cases of non-compliance, and inadequate or slow responses in taking corrective actions to rectify them, on the part of Gulf Air in some critical regulatory requirements.

(b) Although the DGCAM was attempting to ensure regulatory compliance by Gulf Air, it could not accomplish it in some critical regulatory areas, due to inadequate response by the operator.

(c) The regulatory authority and the airline are expected to fulfil complementary roles in maintaining safety of aircraft operations. The evidence indicated inadequacies in the fulfilment of the above, and highlighted the systemic factors in the airline's mechanisms to respond to the regulatory requirements.

8) As described in sections 1.17.11.1, 2.8.1 and 2.9.2, and thereafter, the airline has taken a number of post-accident safety initiatives in the areas such as: go-around procedures, ab-initio training, CRM training, command upgrade training, A320 fleet instructions, recurrent training and checking, instructor selection and training, pilot selection, modification to the A320 automatic flight system, and the flight safety department. Gulf Air has further reported that it is in the process of enhancing its flight crew training, particularly that of A320 aircraft, and introducing more safety initiatives.

3.2 Contributory Factors

The factors contributing to the above accident were identified as a combination of the individual and systemic issues. Any one of these factors, by itself, was insufficient to cause a breakdown of the safety system. Such factors may often remain undetected within a system for a considerable period of time. When these latent conditions combine with local events and environmental circumstances, such as individual factors contributed by “front-line” operators (e.g.: pilots or air traffic controllers) or environmental factors (e.g.: extreme weather conditions), a system failure, such as an accident, may occur.

The investigation showed that no single factor was responsible for the accident to GF-072. The accident was the result of a fatal combination of many contributory factors, both at the individual and systemic levels. All of these factors must be addressed to prevent such an accident happening again.

(1) The individual factors particularly during the approach and final phases of the flight were:

(a) The captain did not adhere to a number of SOPs; such as: significantly higher than standard aircraft speeds during the descent and the first approach; not stabilising the approach on the correct approach path; performing an orbit, a non-standard manoeuvre, close to the runway at low altitude; not performing the correct go-around procedure; etc.

(b) 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 the captain to them, as required by SOP’s.

(c) A perceptual study indicated that during the go-around after the orbit, it appears that the flight crew experienced spatial disorientation, which could have caused the captain to perceive (falsely) that the aircraft was 'pitching up'. He responded by making a 'nose-down' input, and as a result, the aircraft descended and flew into the shallow sea.

(d) Neither the captain nor the first officer perceived, or effectively responded to, the threat of increasing proximity to the ground, in spite of repeated hard GPWS warnings.

(2) The systemic factors, identified at the time of the above accident, which could have led to the above individual factors, were:

(a) Organisational factors (Gulf Air):

(i) A lack of training in CRM contributing to the flight crew not performing as an effective team in operating the aircraft.

(ii) Inadequacy in the airline's A320 training programmes, such as: adherence to SOPs, CFIT, and GPWS responses.

(iii) The airline's flight data analysis system was not functioning satisfactorily, and the flight safety department had a number of deficiencies.

(iv) Cases of non-compliance, and inadequate or slow responses in taking corrective actions to rectify them, on the part of the airline in some critical regulatory areas, were identified during three years preceding the accident.

(b) Safety oversight factors:

A review of about three years preceding the accident indicated that despite intensive efforts, the DGCAM as a regulatory authority could not make the operator comply with some critical regulatory requirements.

Appendix A

INVESTIGATION

The Government of Bahrain immediately invoked the High Supreme Council which appointed the Accident Investigation Board (AIB) on 24 August 2000 under the chairmanship of His Excellency Shaikh Ali bin Khalifa Al-Khalifa, the Minister of Transportation, to investigate into the accident. The National Transportation Safety Board (NTSB) of the USA, the Bureau Enquetes-Accidents (BEA) of France, Bahrain Civil Aviation Affairs (CAA), and the Directorate General of Civil Aviation & Meteorology (DGCAM) of the Sultanate of Oman designated an accredited representative each, in accordance with Annex 13 of the Convention on International Civil Aviation. The Chairman, AIB appointed a Technical Investigation Committee (TIC), consisting of the accredited representatives and chaired by the Undersecretary for CAA, Bahrain. The NTSB representative was designated as Investigator-in-Charge, who reported directly to the Chairman, TIC. Further, two representatives from Egyptian Civil Aviation Authority participated in the investigation as observers.

The TIC was assisted by the accredited representatives' technical advisers and specialists from the industry. The other participating agencies in the investigation were: the Federal Aviation Administration, USA; Airbus Industrie, France; Gulf Air, Bahrain; Gulf Aircraft Maintenance Company, Abu Dhabi; and the CFMI (the engine-manufacturer). Assistance was also provided by the emergency response personnel in Bahrain (including Bahrain International Airport, Bahrain Airport Services, the Ministry of Interior, the Coastguard, Bahrain Defence Force, the Fire and Rescue Services, Bahrain-based airlines, etc.) and the US Navy. Three investigative teams consisting of Operations, Airworthiness and Recorders groups were formed, along with their various sub-groups:

	Group	Sub-group
1.	Operations:	Human Performance and Survival factors, Search/Fire/Rescue/Recovery, Air Traffic Control, and Witnesses.
2.	Airworthiness:	Aircraft Structures, Powerplants and Systems, Aircraft Performance and Maintenance Records.
3.	Recorders:	Cockpit voice Recorder (CVR), and Flight Data Recorder (FDR).

The specialists from the TIC and technical advisers from the industry were assigned to conduct readouts of the FDR and transcribe the CVR at the laboratories of NTSB and BEA. The Recorders-group produced the detailed transcript in English.

A "Factual Information" report was published on 27 March 2001, and posted on the internet. Extensive tests, research and studies were conducted at the laboratories of the NTSB, the Naval Aerospace Research Laboratory of the USA, BEA of France, and at various facilities of Gulf air and Airbus Industrie. The Ministry of Interior of the Kingdom of Bahrain provided a helicopter to conduct the trial flight for the reconstruction study of the final flight path of the accident flight.

An independent investigator from Australia and the human factors specialists from the NTSB assisted the AIB, the TIC, and their advisers in conducting the Analysis phase of the investigation.

In accordance with Annex 13 of the Convention, the draft-Final Report was forwarded to the States participating in the investigation on 10 October 2001. Their comments were received within sixty days. The Sultanate of Oman requested for an extension of time to submit additional comments. This was agreed to. The significant and substantiated comments received from the States participating in the investigation have been incorporated in the Final Report.

The accident investigation report was concluded, and adopted by the Chairman of the Accident Investigation Board on 10 July 2002, and posted on the following websites:

www.bahrainairport.com/GF072investigationreport.htm
www.gulfairco.com

APPENDIX B : COCKPIT VOICE RECORDER TRANSCRIPT

Transcript of a Cockpit Voice Recorder, removed from an AIRBUS A-320 registered A40-EK, which was involved in an accident on August 23 2000, in Bahrain.

* WARNING *

The following represents the transcription of what was intelligible, on the day this report was edited, from the read out of the CVR. This transcript comprises the conversations between the crew members, the radio telephony messages between the crew and the traffic control, and the diverse noises corresponding, for example, to selectors actuators or to alarms.

It should be pointed out to the reader that the recording and the transcription of a CVR only partially reflects the events and the atmosphere in a cockpit. Consequently, such a document should be interpreted very carefully.

* MAIN LEGEND *

UTC	: Aircraft UTC time
➪	: Communication from the crew to the ATC
CMV	: Voice identified as the Cockpit Mechanical Voice
PA	: Public address (communication from the pilots or flight attendants) on a specific channel
F/A	: Voice identified as a Flight Attendant (1, 2, …)
(*)	: Unintelligible word or sentences
(@)	: Sounds, alarms
(…)	: General conversation (non pertinent conversation or slang for example)
(#)	: Exclamations
( )	: Words or sentence which are still doubtful
example	: Words or sentences in italic in the remarks column are translated from the Arabic

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
15 h 59 min 41 s	**START OF RECORDING**				
16 h 21 min 35 s	**START OF TRANSCRIPT**				
21 min 37 s	Non-pertinent conversation between captain and first officer.				
21 min 48 s			Gulf Air 072 uh, self navigation for Runway One Two is approved. Three point five as well approved and Bahrain Approach One Two Seven Eight Five approved.		Three point five = 3,500 feet One Two Seven Eight Five = 127.85 MHz
21 min 59 s	➪ Gulf Air 072 confirm we can go for Runway One Two.				
16 h 22 min 02 s			Affirmative. Three approvals you have: Direct for One Two. Three point five approved. One Two Seven Eight Five approved.		One Two = Runway 12 Three point five = 3,500 feet One Two Seven Eight Five = 127.85 MHz
22 min 09 s	➪ Have a good day.				
22 min 10 s	Call Bahrain and tell them are we going for Runway uh One Two.				
22 min 16 s	(*)				
22 min 19 s		➪ Bahrain approach, salam alaykom, Gulf Air 072 . We copied information Tango and uh, Runway One Two is approved.			

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
22 min 28 s			Gulf Air 072 Bahrain Approach, good evening to you. Identified on handover. (*) Runway One Two cleared self position and uh, as you're cleared by Dhahran. Confirm Three Thousand Five Hundred feet.		
22 min 42 s		(*)			
22 min 44 s	Tell them we are cleared to Seven Thousand.				Seven Thousand = 7,000 feet
22 min 46 s		➪ We are cleared to Seven Thousand, Gulf Air 072.			Seven Thousand = 7,000 feet
22 min 50 s			Roger Gulf Air 072. Continue descent Three Thousand Five Hundred feet on the QNH One Zero Zero One. Cleared self position Runway One Two. Request souls on board.		Descent = descent to QNH One Zero Zero One = QNH 1001hP
22 min 59 s		➪ Clear self positioning Runway One Two. Continue descent Three Thousand Five Hundred, and we have One Four Three souls on board, Gulf Air 072.			Three Thousand Five Hundred = 3,500 feet
16 h 23 min 08 s			Thank you.		
23 min 09 s	Approach checklist please.				
23 min 16 s		Briefing?			
23 min 18 s	Confirmed.				
23 min 19 s		ECAM status?			

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
23 min 20 s	Checked.				
23 min 21 s		(*)	Gulf Air 072, continue descent to One Thousand Five Hundred feet. Report established (the) VOR/DME Runway One Two radial Three Zero One.		Three Zero One = 301 degrees established = established on
23 min 28 s		➪ Continue descent to One Thousand Five Hundred uh, report established on the VOR/DME Runway One Two, Gulf Air 072.			One Thousand Five Hundred uh = 1,500 feet
23 min 36 s		V bugs?			
23 min 37 s	V bugs, One Three Six, Two Zero Six, set.				One Three Six, Two Zero Six = 136 knots and 206 knots
23 min 41 s		Checked. seatbelts?			
23 min 43 s	On.				
23 min 44 s		Baro MDA?			
23 min 46 s	Okaaay, baro One Zero Zero One, Four Seven Zero				One Zero Zero One = 1001 hP Four Seven Zero = 470 feet
23 min 53 s				(@)	Single chime similar to master caution aural.
23 min 54 s		(*) ECAM			
23 min 56 s	We know about that.				
23 min 58 s		Leave it?			

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
16 h 24 min 09 s		(*). uh huh….			Pilots start to use hot mikes
24 min 10 s		(Continue).			
24 min 11 s		(Stand by please cabin pressure low differential. Clear?)			
24 min 16 s	Raw VOR for me please.				
24 min 23 s		Ya.			
24 min 26 s					Pilots select interphone position
24 min 28 s	Okay, speed ALT STAR approach nav.				
24 min 31 s		Check.			
24 min 34 s				(@)	Sound of click similar to seatbelt buckle.
24 min 38 s	Now you see you have to be ready, for all this, okay? If (it) change on you all of a sudden, you don't say, I'll go. You have to know DME, if you can make it or not. Okay?				
24 min 50 s		Okay.			
24 min 51 s	Now, I've just changed all the flight plan, RAD NAV, everything for you, before you even blink.				
24 min 58 s	Yeah? Okay Ammy?				
16 h 25 min 00 s		Okay Ammy.			

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
25 min 02 s	Ammek mawlaak.				
25 min 03 s		Okay sir.			
25 min 05 s	Activate approach is One Three Six. It's already done. Magenta high and positive.	(high) (*) checked.			
25 min 11 s		(*) Checked.			
25 min 12 s	And Approach NAV, final green.				
25 min 14 s		Checked green, check.			
25 min 15 s	Final descent is seven - DME.				
25 min 18 s		Check.			
25 min 20 s					Sound of unidentifiable intermittent tone.
25 min 31 s	ALT green.				
25 min 32 s		Check.			
25 min 34 s					Sound of unidentifiable intermittent tone.
25 min 37 s	Call established.				Call established on the VOR
25 min 41 s		➪ Gulf Air 072, established on the VOR.			
25 min 45 s			Gulf Air 072, clear VOR/DME Runway One Two. Seven mile from touchdown. Contact tower One One Eight Five.		One One Eight Five = 118.5 MHz
25 min 51 s		➪ Clear for the approach and uh contact Tower One			Contact Tower One One Eight Five = Contact tower

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
		One Eight Five, Gulf Air 072.			on 118.5 MHz
16 h 26 min 00 s	Final, green.				
26 min 02 s		Check.			
26 min 04 s		➪Bahrain Tower, salam alaykom, Gulf Air 072, Eight -DME established.			
26 min 08 s			Gulf Air 072, cleared to land Runway One Two. Wind Zero Nine Zero Eight.		Wind Zero Nine Zero Eight = 090 degrees/8 knots
26 min 13 s	Flaps one.	➪ Cleared to land Runway One Two, Gulf Air 072			
26 min 17 s		Speed checked, Flaps “1”.			
26 min 20 s		(Ehsan) status clear .			
26 min 22 s	Clear status, gear down.				
26 min 25 s				(@)	Sound similar to landing gear being activated.
26 min 26 s		Checked gear down.			
26 min 28 s	(*) step.				
26 min 30 s		Descent.			
26 min 36 s		Is (down or done)			
26 min 37 s	Okay, visual with airfield.				
26 min 39 s		Check.			
26 min 42 s		Gears are down and flaps at “1”.			
26 min 44 s				(@)	[Sound of] "Cavalry charge" similar to auto-

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
					pilot disconnect signal.
26 min 45 s	Auto-pilot's coming off.				
26 min 46 s		Check.			
26 min 47 s	Flight directors off.				
26 min 49 s 26 min 50 s 26 min 51 s 26 min 53 s 26 min 54 s 26 min 56 s	Have to be stabilized by Five Hundred feet. Okay.	Off. Yes. We're on radial.		(CMV) One thousand.	(PA) Ladies and gentlemen, the no-smoking sign has now been illuminated. Please ensure that you carefully extinguish your cigarettes. No further smoking please until you are inside the designated smoking areas of the airport terminal building. Thank you. One Thousand = 1,000 Feet
16 h 27 min 06 s	(#), We're not gonna make it.				
27 min 08 s		Yeah.			
27 min 09 s	Flaps Two.				
27 min 10 s		(Speed), Check Flaps Two.			
27 min 13 s	We're not gonna make it (bwana).				
27 min 15 s	(#)				
27 min 19 s		Mushkella. flaps at Two.			
27 min 23 s	Tell him to do a Three Six Zero left.				Three Six Zero = 360 degrees orbit
27 min 25 s		➪ Gulf Air 072 request			

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
		Three Six Zero to the left.			
27 min 29 s			Approved, Sir.		
27 min 31 s		➪ Approved, Gulf Air 072.			
27 min 33 s	Flaps Three.				
27 min 34 s		(Speed) checked, Flaps Three.			
27 min 38 s				(@)	Sound similar to increase in engine RPM.
27 min 44 s	Flaps full.				
27 min 45 s		Speed check, Flaps full.			
27 min 47 s				(@)	Sound similar to decrease in engine RPM.
27 min 51 s		Flaps at full.			
27 min 53 s	Thanks.				
27 min 54 s		and Seven Hundred.			Seven Hundred = 700 feet
16 h 28 min 17 s	Landing checklist.				
28 min 23 s		Cabin crew?			
28 min 24 s	Advised.	Auto-thrust?			
28 min 25 s	Speed.				
28 min 26 s		ECAM memo?			
28 min 27 s	Landing, no blue.				
28 min 28 s		Landing checklist completed.			
28 min 41 s				(CMV) Four Hundred.	Four Hundred = 400 feet
28 min 43 s		(*) Okay.			

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
28 min 47 s		Runway in sight …three hundred.			Three hundred = 300 Feet
28 min 48 s			Gulf Air 072, cleared to land Runway One Two.		
28 min 52 s		➪ Cleared to land Runway One Two, Gulf Air 072.			
28 min 57 s	(#) We overshot it (*).				
28 min 59 s				(@)	Sound similar to increase in engine RPM.
16 h 29 min 04 s	(@)				Sound of tongue clicking.
29 min 07 s	Tell him going around.				
29 min 08 s		➪ Gulf Air 072, going around.			
29 min 10 s				(@)	Sound of selector similar to throttle pushed to the wall followed by sound similar to increase in engine RPM.
29 min 11 s			I can see that, 072. Sir, uh would you like radar vectors for final again?		072 = Gulf Air 072
29 min 15 s	Go around flaps.				
29 min 17 s	Yes.				
29 min 18 s	Go around flaps set.	➪ (*) We'd like radar vectors, Gulf Air 072.			
29 min 22 s	Gear up.				
29 min 23 s				(@)	Sound similar to landing gear operation.
29 min 25 s		(Speed) check positive climb gear up.	Roger uh, fly heading Three Hundred uh, climb Two		Three Hundred = 300 degrees

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
		climb gear up.	Thousand Five Hundred feet.		degrees
29 min 30 s		➪ Heading Three Hundred climb Two Thousand Five Hundred feet. Gulf Air 072.			Three Hundred = 300 degrees
29 min 33 s	Heading?				
29 min 34 s		Yes, Three Hundred.			Three Hundred = 300 degrees
29 min 37 s	Three Hundred?				Three Hundred = 300 degrees
29 min 38 s		Zero yes. Right? Left.			Right? Left = Right? or Left
29 min 41 s				(@)	Continuous repetitive chime (CRC) similar to over speed warning.
29 min 42 s 29 min 44 s		Speed, Over speed limit (*)	And contact approach, One Two Seven Eight Five Sir.		One Two Seven Eight Five = 127.85 MHz
29 min 46 s	(#).				
29 min 47 s 29 min 48 s		➪ One Two Seven Eight Five.		(CMV) priority left.	One Two Seven Eight Five = 127.85 MHz
29 min 50 s		Speed checks, Flaps Three.			
29 min 51 s				(CMV) Sink rate.	
29 min 52 s	Flaps up.			(CMV) Whoop whoop pull up	
29 min 53 s				(CMV) Whoop whoop pull up	
29 min 54 s				(CMV) Whoop whoop pull up	End of CRC
29 min 55 s					
29 min 56 s				(@)(CMV) Whoop whoop pull	Start of CRC

UTC time	CPT	F/O	RADAR/TWR	CMV and sounds in cockpit	Remarks
				up	
29 min 57 s	(#)			(CMV) Whoop whoop pull up	
29 min 58 s		Gear's up, flaps..		(CMV) Whoop whoop pull up	
29 min 59 s	Flaps all the way.			(CMV) Whoop whoop pull up	End of CRC (59,5 s)
16 h 30 min 00 s		Zero.		(@)(CMV) Whoop whoop pull up	Start of CRC (00,5 s)
30 min 01 s				(CMV) Whoop whoop pull up	
16 h 30 min 02	**END OF RECORDING / TRANSCRIPT**				

O APPENDIX D

OPERATIONS MANUAL
VOLUME 6
APPENDIX A
A320 ROUTE MANUAL 04 Oct 2000

GULFAIR

A320 FLEET INSTRUCTION NO. 14/2000 (Re-Issue #1)

SUBJECT: STANDARD OPERATING PROCEDURES (SOP).

With immediate effect the following SOP's are to be implemented:

1) Speed Control Below FL 100 or 10,000ft AMSL:

a) A speed limit of 250 knots below FL 100 or 10,000ft AMSL is to be observed for normal operations.

b) Exceptionally, at the request of ATC, a higher speed may be maintained below FL 100 or 10,000ft **AMSL**, but must be reduced to 250 Knots or less prior to descending below FL 50 or 5,000ft **AAL**.

c) For higher altitude airports (for example Nairobi, Sanaa, Tehran, Shiraz), speed should be reduced to 250 Knots or less prior to descending below 10,000ft **AAL**

2) Stabilised Approach Criteria:

a) In normal operation, it is recommended that the aeroplane is stabilised in the landing configuration by the outer marker (or an equivalent point) for an ILS approach, or by the FAF for a non-precision approach.

b) In IMC the aircraft must be stabilised in the landing configuration no later than 1000ft AAL. If this cannot be achieved the crew must consider a missed approach.

c) In VMC, and for Visual Approaches, the aircraft must be stabilised in the landing configuration no later than 500ft AAL. If this cannot be achieved the crew must consider a missed approach.

3) **Visual Manoeuvring In The Vicinity of An Airport:**

a) All visual manoeuvring in the vicinity of an airport of intended landing is subject to the limitations for Circling and Visual Approaches in OM 8.1.3.15 and 16 (AOM) and must be flown in accordance with the procedures specified in FCOM 3.03.19 8/9 and 3.03.20 1/2.

b) Once the aircraft is established and descending on the final approach to the runway of intended landing, 360 degrees turns and other manoeuvres for descent profile adjustment are not permitted.

All pilots are reminded of their personal responsibility to ensure that the Company's aeroplanes are operated in accordance with published SOPs unless exceptional circumstances apply.

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.

A320 FLEET INSTRUCTION NO. 18/2000

FLIGHT DIRECTOR USAGE DURING NON-PRECISION APPROACH

Reasons for Revision

As a result of feed-back from experience during line flying this Fleet Instruction has been amended in two respects:

Firstly, Airbus advice on the procedure appeared to give an option for FD selection at MDA, when continuing to land, by using the word 'can'(continue for a visual approach...). There is no option; FDs will be switched off when visual and landing.

Secondly, there has been some confusion about the call for changing from TRACK-FPA to HDG-V/S. Due to unfamiliarity with the procedure, some pilots have been trying to select a heading and a V/S when the "HDG-V/S' call has been made. We shall adopt the procedure as outlined in FCOM 3.03.90 p2, under 'ON/OFF' with the exception that "TRACK-FPA" will be used instead of "BIRD".

The Airbus wording of item 4 of the Procedure has been changed slightly to reflect that 'the pilot' does not make FCU selections when flying manually. (PNF selects as ordered by PF)

Background

Prior to GF adopting Airbus SOPs in 1999 the procedure for FD usage during a NPA was to leave FDs ON after MDA so that guidance would be available in the event of GA. FCOM 3 does not give specific instructions at MDA apart from "continue as for visual approach". We asked Airbus Industrie to clarify the exact procedure for FD switching and modes when continuing approach after MDA, and their response is outlined as follows. Our notes are included in italics.

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GULF AIR

Procedure

1. If ground references are visible, the pilot will continue for a visual approach and the FDs will be disconnected (refer to SOP 3.03.20.)

   PF will call "FDs OFF"; PNF only will action

2. If during the visual approach the pilot decides to go-around, GA procedure without FD will apply (refer to SOP 3.03.23).

   You are reminded that in TK-FPA mode the aircraft reference symbols are dimmed (yellow surround disappears).

3. Selection of HDG-V/S mode after go-around initiation is recommended.

   After L/G has been selected up, PF will call "TRACK-FPA OFF".

4. The PNF will re-engage FDs when passing the go-around acceleration altitude.

   This is in accordance with the procedure for GA with FD OFF and will be called for by PF and actioned by PNF after target speed has been selected to Green Dot and thrust levers have been moved to the CL detent.

Notes

Airbus Industrie recommends implementation of the modification for automatic return of FD bars at go around initiation. The modification has been requested and is expected to be incorporated within the next few months.

Appendix E

Gulf Air Flight GF-072 Perceptual Study

23 AUGUST 2000
Gulf Air Airbus A320-212 (A40-EK)
NIGHT LANDING

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Aircraft data from the FDR that influences spatial orientation were analyzed and evaluated at NAMRL at the request of the NTSB, POC: Bart Elias, eliasb@ntsb.gov.

Summary

This mishap represents a tragic, but scientifically interesting, accident in which a series of events led to a physiologically normal misperception of pitch orientation by the pilots in control of the aircraft. Due in part to the compelling nature of this false information, and in part due to the task saturation created by multiple cockpit distractions, the pilots did not perceive the true attitude of the aircraft. Indeed, based on our model of the pilots' perception of pitch up, the pilot in command provided inputs that resulted in further pitch down changes resulting in impact with the water.

Detailed Report

The perceptual model used to develop this report is built upon 60 years of research conducted primarily at NAMRL and supported by other labs around the world using a collection of ground-based acceleration devices and in-flight aircraft experiments to corroborate and extend the model. This model predicts the perceived orientation of pilots in response to acceleration conditions experienced in the aviation and space environments. The model assumes that the pilot is not receiving visual attitude information.

Background

Normal perceived orientation is based primarily on information from the senses of vision, inner ear organ of balance (vestibular system) and our skin-muscle-joint (somatosensory) receptors. All provide accurate, concordant, redundant orientation information in our day-to-day terrestrial activities. The problem occurs in the aeronautical environment where two of these systems (vestibular and somatosensory systems, collectively referred to as the “seat-of-the-pants” sensation by pilots) provide false but concordant, and hence compelling orientation information every time the aircraft is in any other condition but smooth, straight-and-level flight.

It is only with visual orientation cues that pilots overcome the illusions created by the seat-of-the-pants sensations, and even then not always. Whenever visual orientation information is absent, the brain continues to compute orientation with the only information available, namely the continuous information from the vestibular and somatosensory systems.

Physical Forces Producing Pitch Up Sensation

There are many in-flight forces that can produce a sensation of pitch up. It was an unfortunate condition of this flight that the pilots of Gulf Air 072 were exposed to several physical factors all acting in concert and some synergistically to produce a significant false pitch up sensation of approximately 12 degrees when in reality the aircraft was only pitched up 5 degrees (Figure 1, upper left, Perceived Pitch).

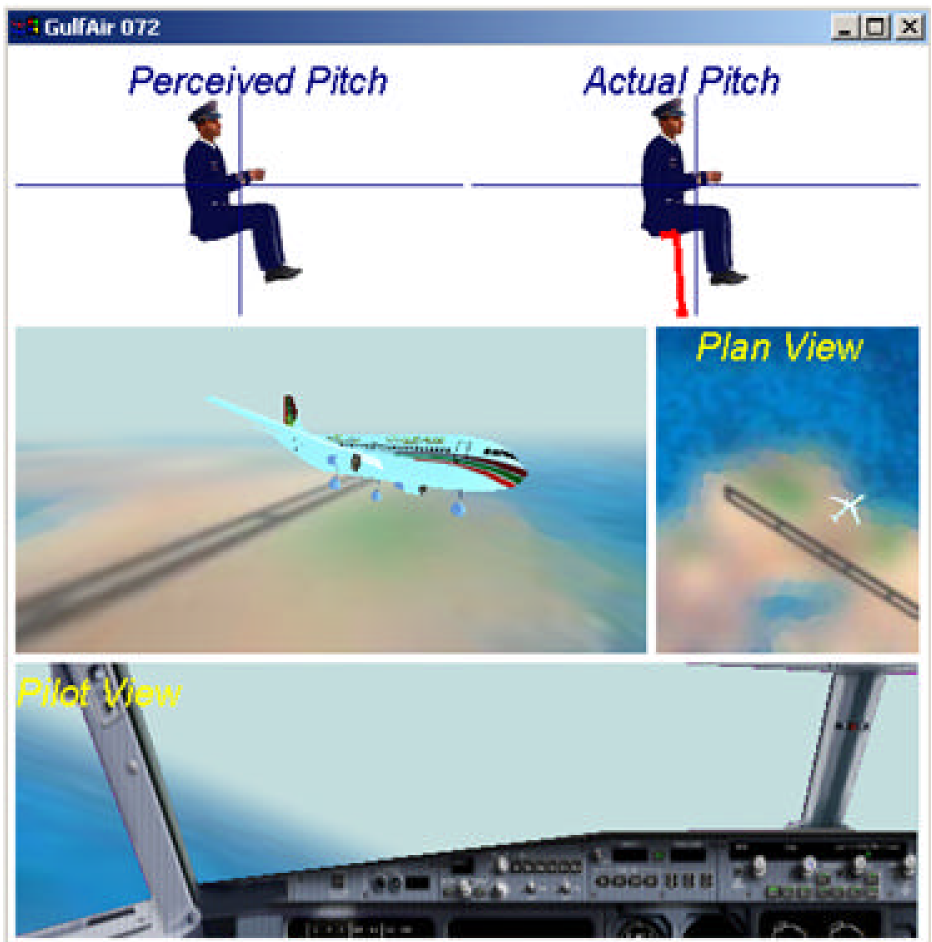


Figure 1: Perceived Pitch versus Actual Pitch just prior to stick forward (t=1929:43)
(Red Arrows in Actual Pitch panel are the Gx and Gz acceleration vectors)

The following forces contribute to the increased pitch up sensation.

1) The aircraft was linearly accelerating from the beginning of the second go-around maneuver (t= 1929:07s) until impact (Figure 2, Gx). This contributed to changing the direction of the resultant force vector from directly in-line with the vertical torso of the pilot to a rearward direction (Figure 4, blue arrows). This force contributes to the somatogravic illusion, a misperception of attitude that results in frequent mishaps. There is a time lag associated with this perception and so the time of loss of visual orientation cues is important. A secondary effect of the maintained linear acceleration is to increase the magnitude of the overall resultant vector (gravito-inertial force (GIF)), which contributes to the G-excess effect.

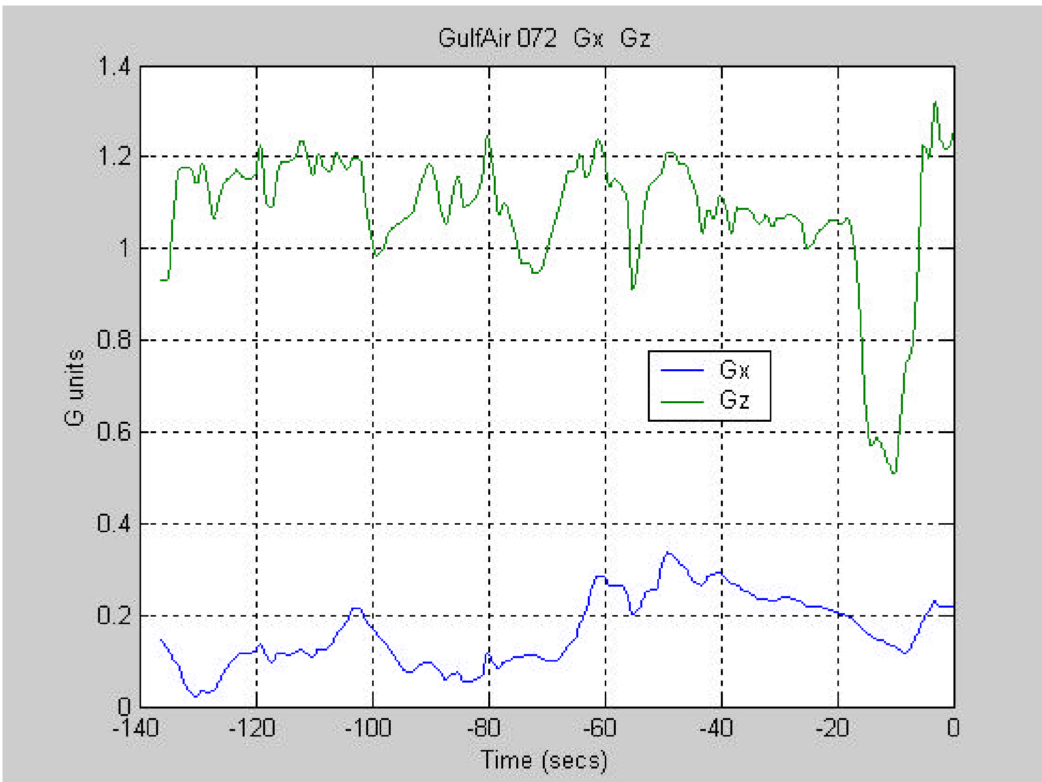


Figure 2: Gx and Gz Forces versus Time to impact

2) The angle of bank of the aircraft increases the magnitude of the resultant force vector (and even more so when vertical velocity was increasing as in this mishap). This force contributes to the G-excess effect (Guedry et. al, 1972) and results in an increased perception of pitch up. The magnitude of the pitch up percept depends on the increase in the GIF and on head position. In this mishap we are assuming that the pilot has his head inclined slightly downward by about 15 degrees that reduces the magnitude of the pitch up percept. As with the somatogravic illusion there is a time lag in both the onset and offset of the perception following application of the increased "G" force. This is factored into the dynamics of the perceptual model.

3) The rate of climb after the initiation of the second go around results in a mild but maintained vertical acceleration that contributes to an increase in the overall resultant force vector.

4) Angular acceleration due to changes in aircraft pitch synergistically affects the somatogravic pitch illusion when the angular acceleration acts in the same direction as the somatogravic pitch illusion. On the other hand, strong linear acceleration can block the affects of the angular displacement (McGrath, 1990). In this mishap, the overall resultant force vector was rapidly decreasing in magnitude at the same time the aircraft pitched down resulting in a pitching forward perception (Figure 3). This explains why in Figure 3 the perceived pitch sensation does NOT follow the GIF angle. The preceding turn associated with the second go around contributes to this difference in two ways – first from the direct G excess pitch up and secondly by contributing to a larger change in the overall magnitude of the GIF.

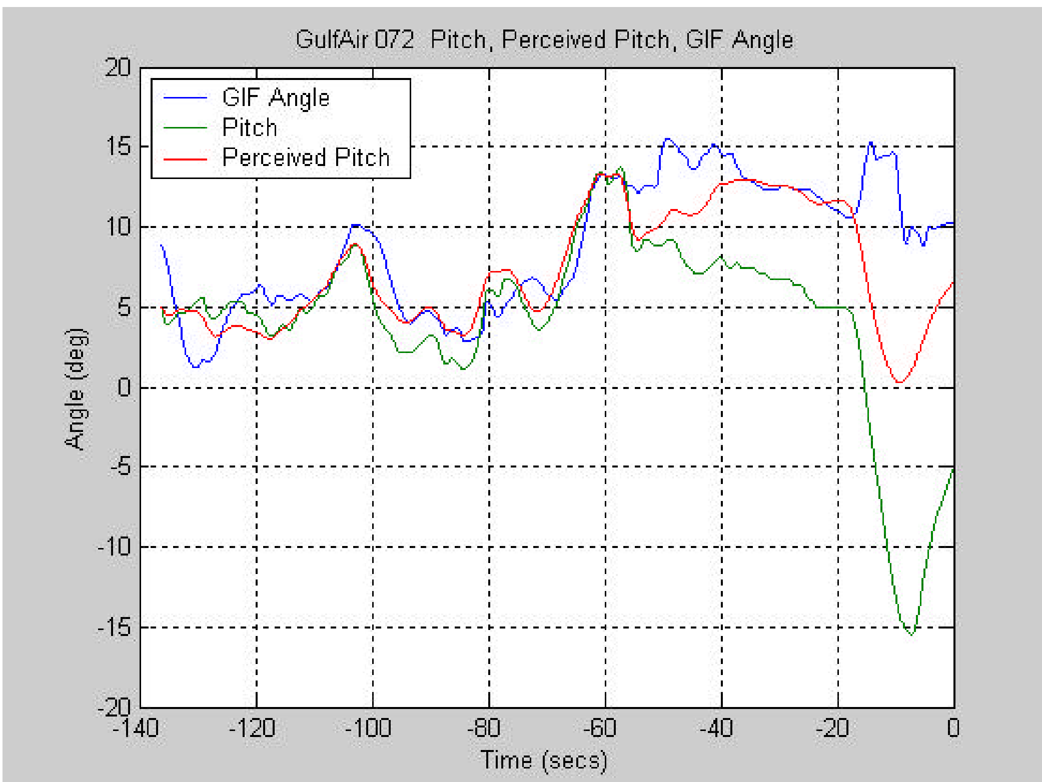


Figure 3: Pitch, Perceived Pitch, GIF Angle versus Time to Impact

The dynamics of the first three physical forces mentioned above are summarized in the time course plot (Figure 4) showing the magnitude of the resultant force vector (GIF) and the angle this vector makes with respect to the upright (head-to-seat) axis of the seated pilot. The only factor missing is the pitch stimulus associated with angular acceleration about the pitch axis (# 4 physical force above).

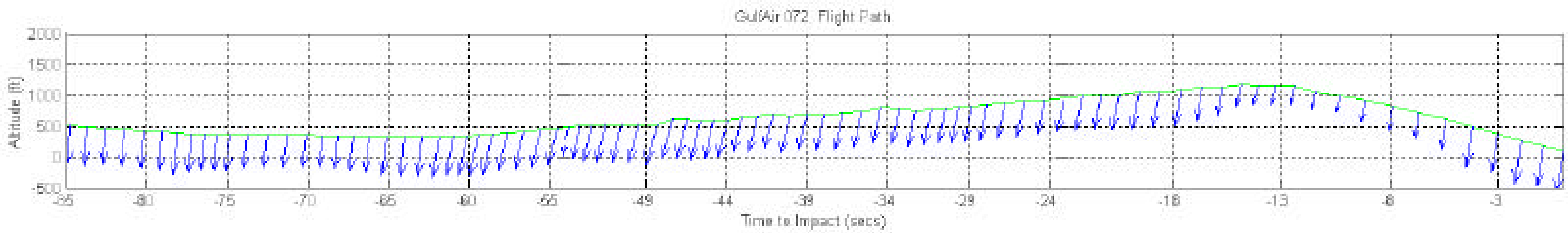


Figure 4: Flight Path of Gulf Air 072 versus Time to impact and Resultant Force Vector (GIF)

The overwhelming nature of the pitch illusion is evidenced by the fact that the pilot in command did NOT follow the recommended GPWS procedure of "Pull up to full back stick and maintain", since he believed he was approximately level and so only partially pulled the stick, (Figure 5; i.e. he pulled to approximately 11.7 degrees aft vice the maximum capability of 16 degrees aft, Figure 6)

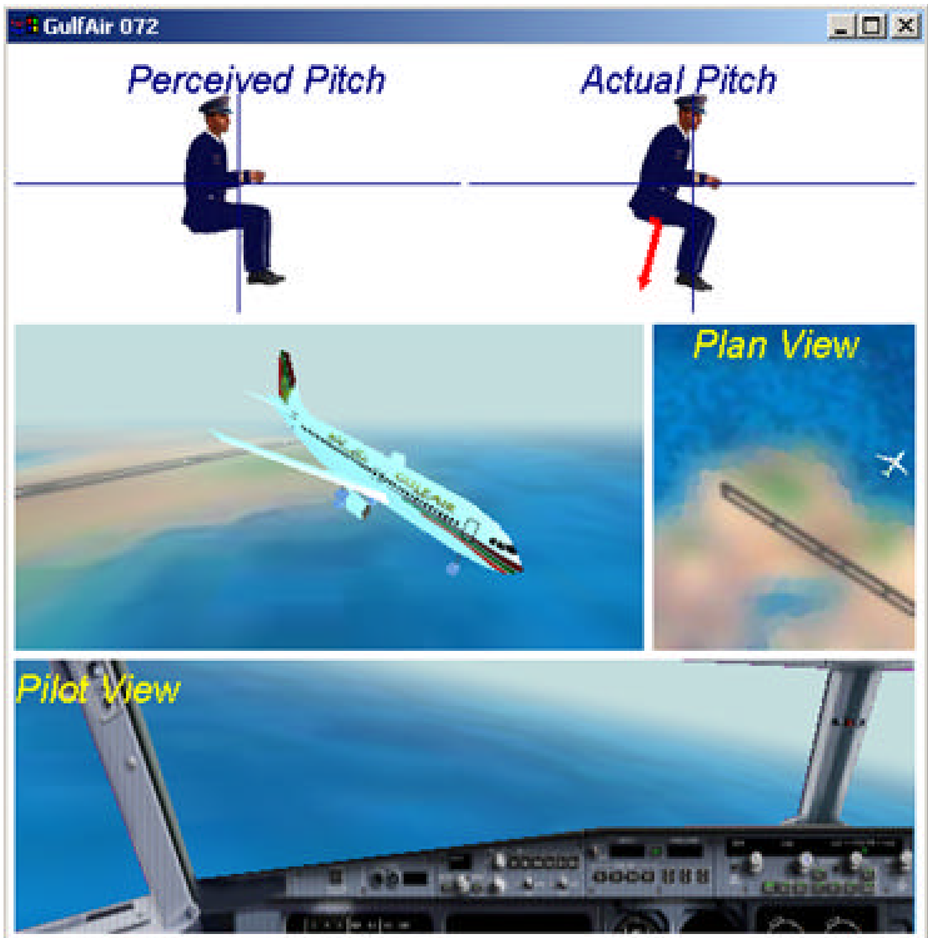


Figure 5: Perceived Pitch versus Actual Pitch just prior to stick back (t=1929:53)

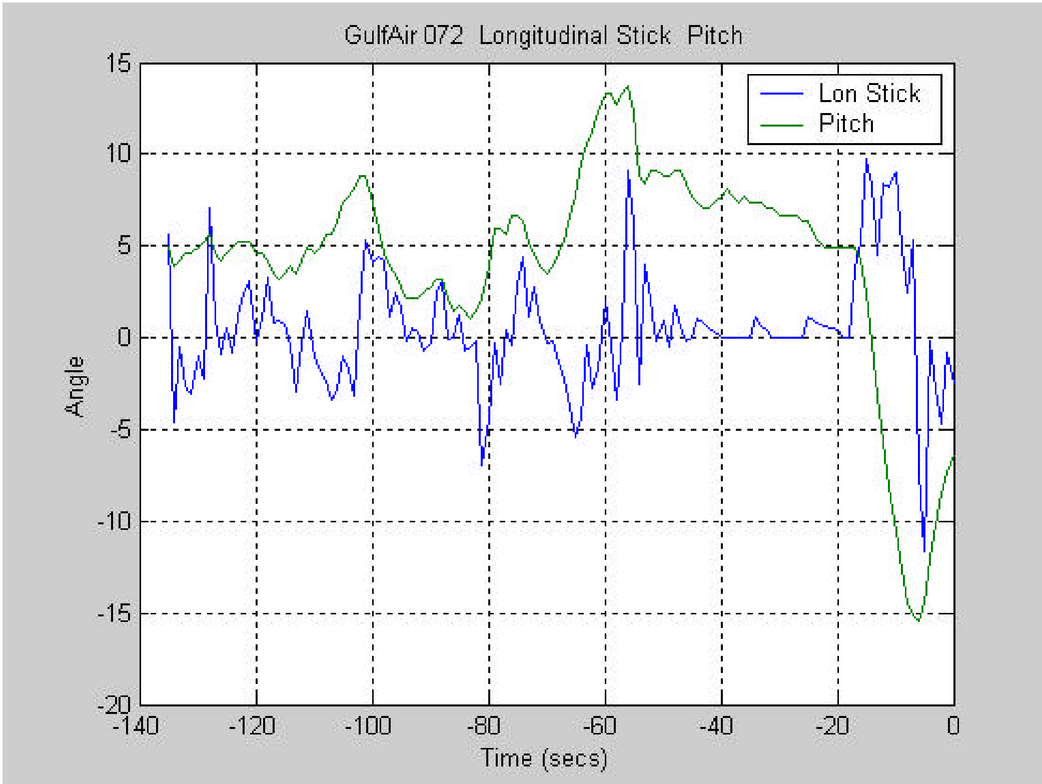


Figure 6: Pitch, Longitudinal Stick Position versus Time to Impact

An important factor in predicting the perception of the pilot is determining the point at which the pilots no longer are attending to, or receiving, accurate outside and inside orientation cues. This is addressed in the following section.

Time of Loss of External Visual Orientation Cues

Given the altitude, night visibility conditions and the available view from the cockpit, the NAMRL video reconstruction places the time at which the pilot could not obtain visual cues from looking outside as approx 21 sec before impact (Figure 7, t=1929:41). However, we believe that the pilot in command from the beginning of the second go around (t= 1929:07) until impact had his FULL attention directed inside the cockpit. From the point at which he instructed the first officer to inform ATC of his intention to make a second go around until impact he was attending to power application, then flaps, then landing gear, aircraft heading issues and finally other multiple in-cockpit actions required to deal with master warnings associated with overspeed and sink rate. Despite the presence of the primary flight display (PFD) we assume that the pilot was NOT allocating attention to the PFD. Both PFDs are located outboard on the cockpit instrumentation panel and the location of the items to which the pilot was attending from the point of the second go around are centrally located and most are in the center of the cockpit.

Establishing the time of the second go around as the point at which the pilot was fully absorbed with in-cockpit tasks is of significance to the perceptual model for several reasons: – first the highest angle of bank occurs at this point and the G excess effect contributes to the early portion of the pitch up sensation, thereby “setting the stage” for the somatogravic illusion; secondly, the go around is associated with other physical forces mentioned in the above section. These forces have a synergistic influence on perceived pitch during the final 18 seconds when the GIF influence on the pitch sensation decreases as the canal input from the pitch forward comes into play.

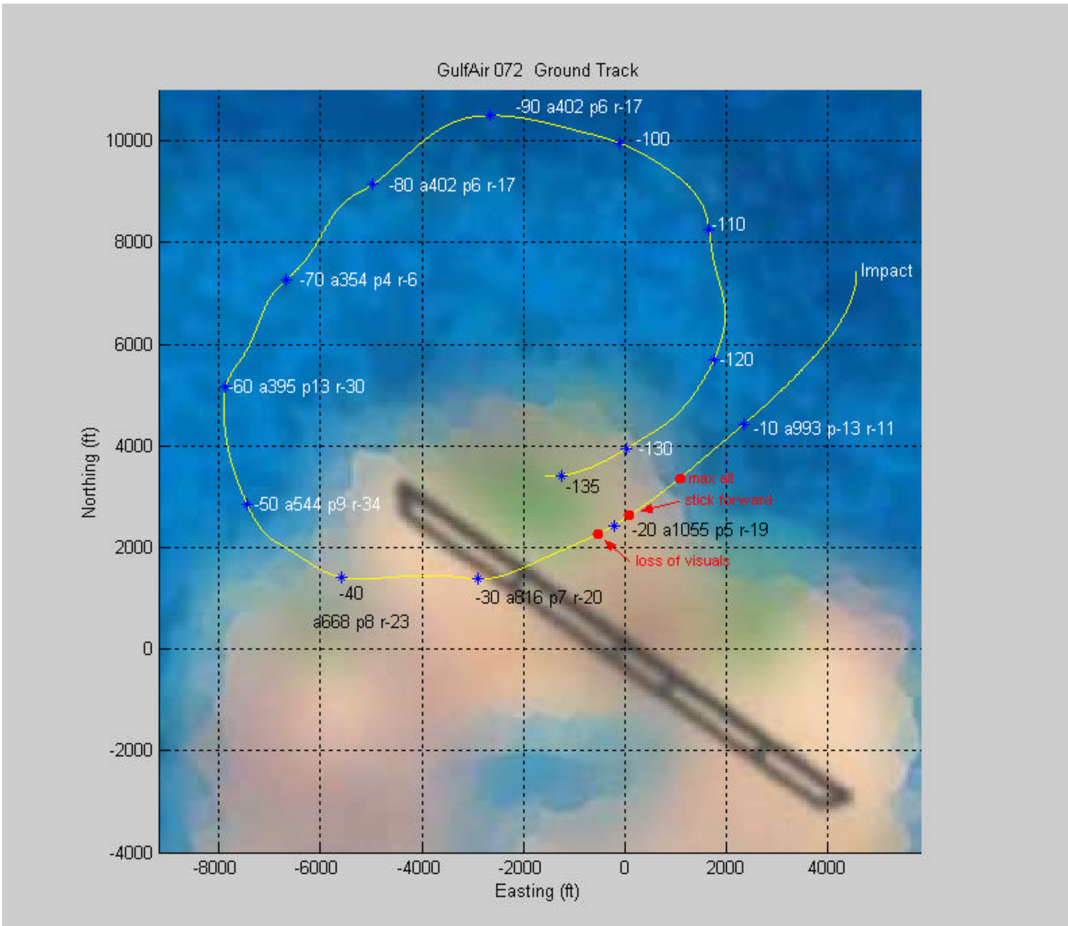


Figure 7: Flight Path (time to impact, altitude, pitch, roll)

Workload Issues

There are a multitude of factors that have been addressed by many human factors experts such as – tunneling of attention, task saturation, novelty of events and so on. There is little doubt that a chain of events is involved in this mishap - the pilot was too high leading to the first unsuccessful approach; the 360-degree orbit not achieving expected result; the probability of geographic disorientation as evidenced by the first officer calling out “runway in sight” and the pilot in command taking about ten seconds to perceive and remark “we overshot it” while dealing with a relatively inexperienced first officer and feeling the need to “do it all”; and a first officer who had to deal with several novel unexpected conditions. ALL of these factors were superimposed on a strong illusion created by several physical forces acting in concert. This assists in explaining why neither pilot directed sufficient attention to the PFD.

In the military we work on several such mishaps EVERY year. The conclusion of the mishap board is generally the same – “the pilot failed to maintain a proper instrument scan”. Unfortunately, this has NOT reduced the frequency of these mishaps. A recent trend in higher-level endorsements has been the inclusion of recommendations for software solutions, new displays that provide continuous non-visual information, and improved training.

Figure 1: Instrument Approach Chart of Bahrain Runway 12 VOR/DME Procedure

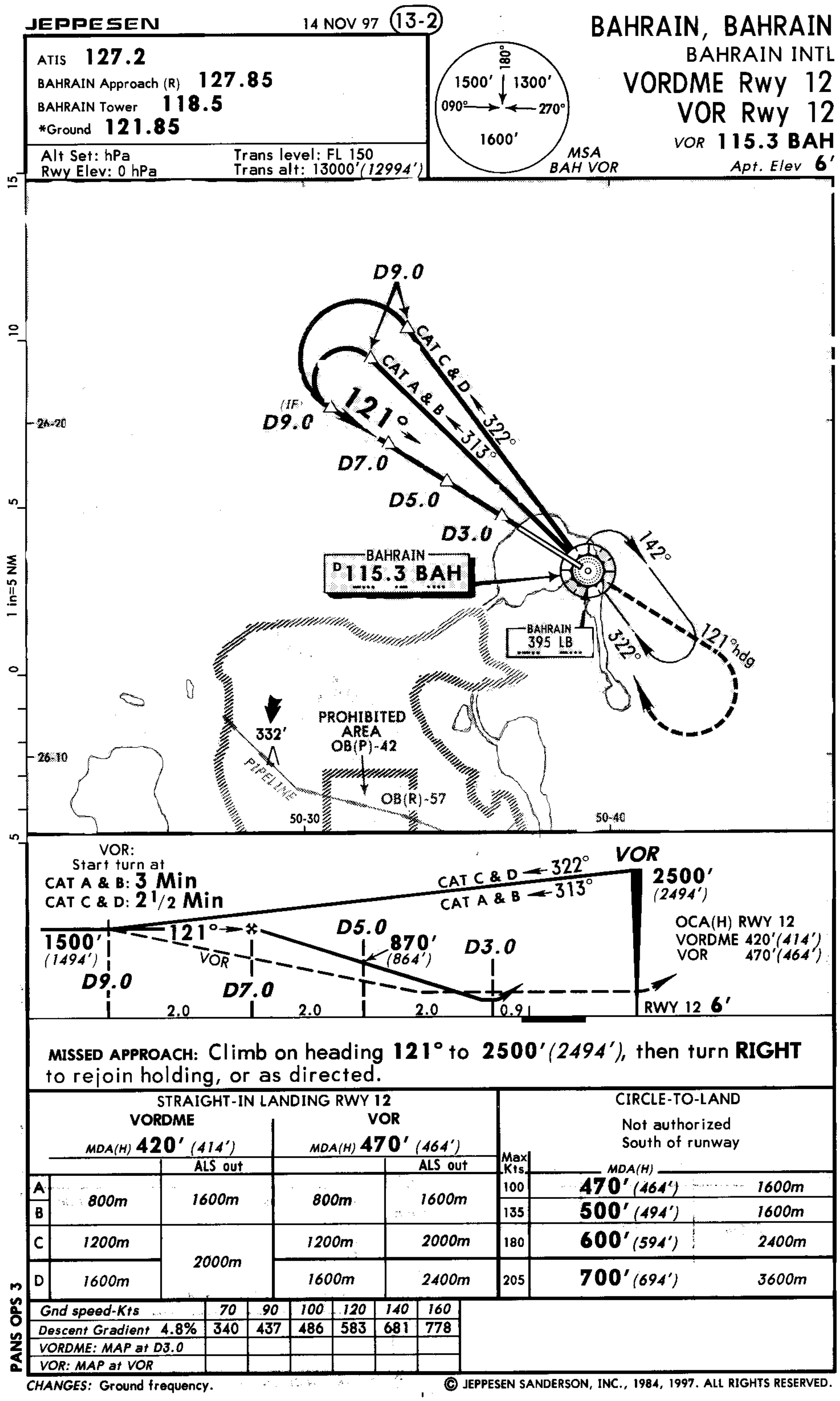


Figure 2. Overhead view of GF-072 trajectory with selected FDR, CVR, and ATC communication excerpts.

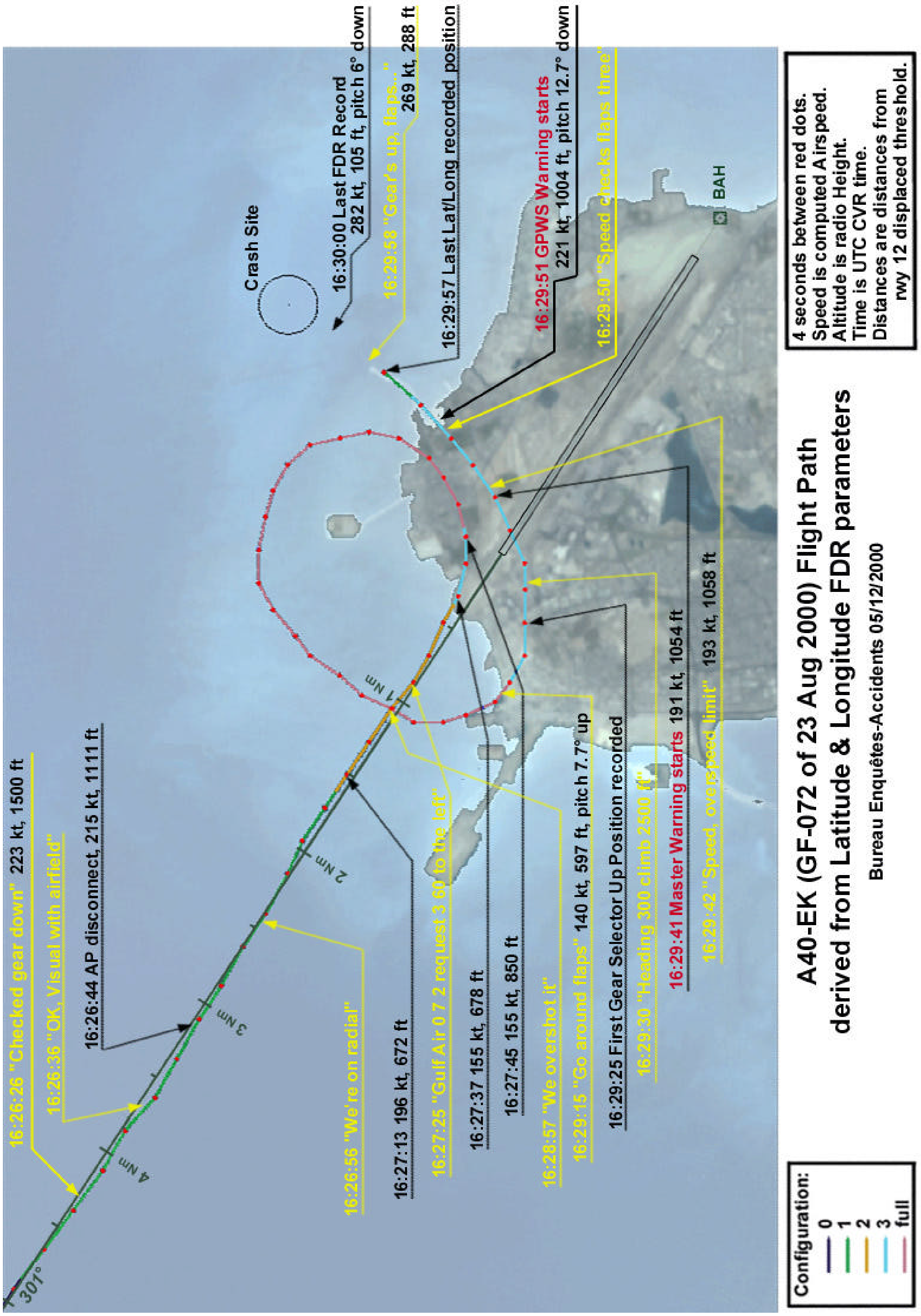


Figure 3. Side view (vertical profile) of GF-072 trajectory.

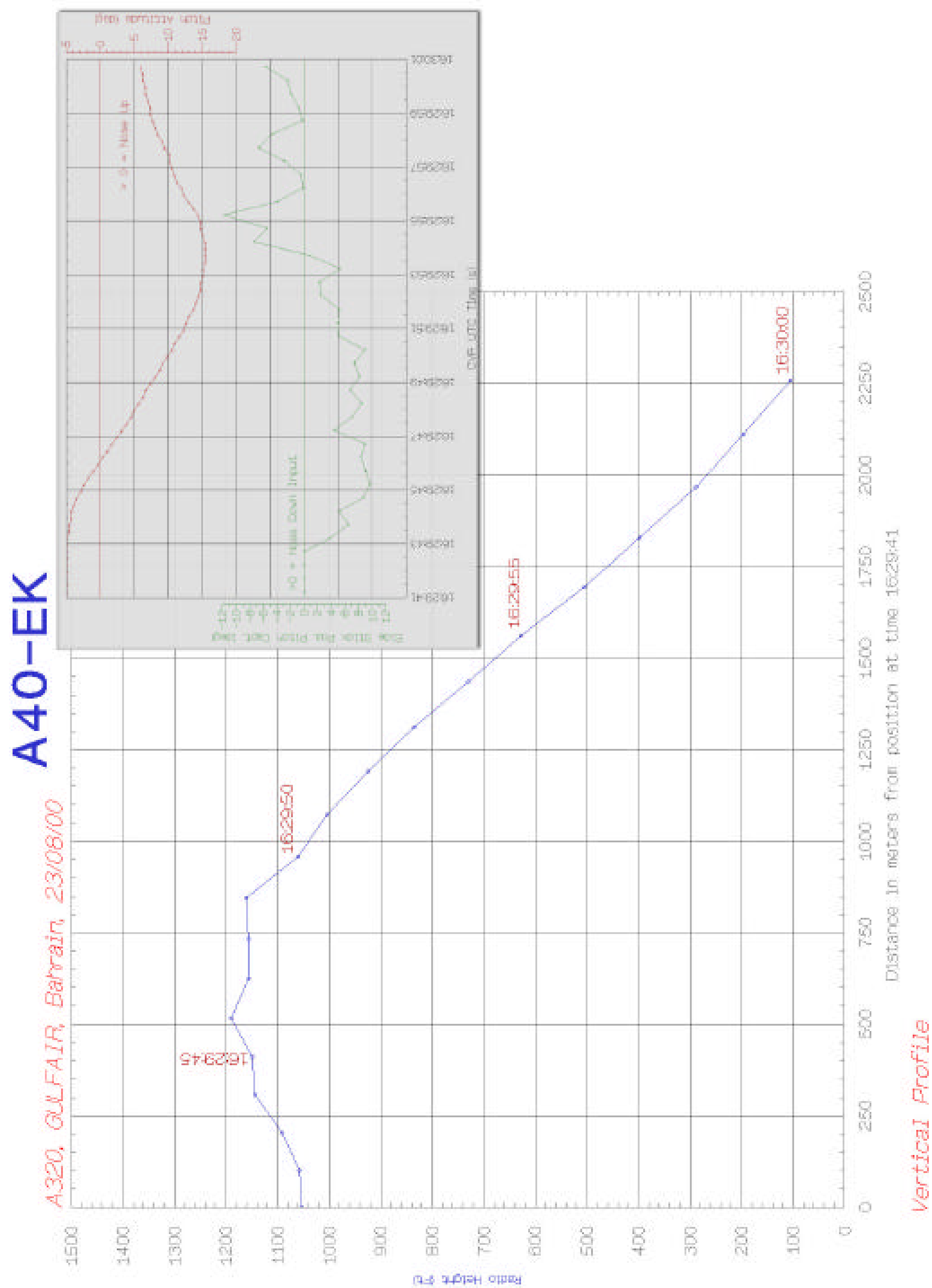


Figure 4: Sidestick spring force vs. deflection

Pitch

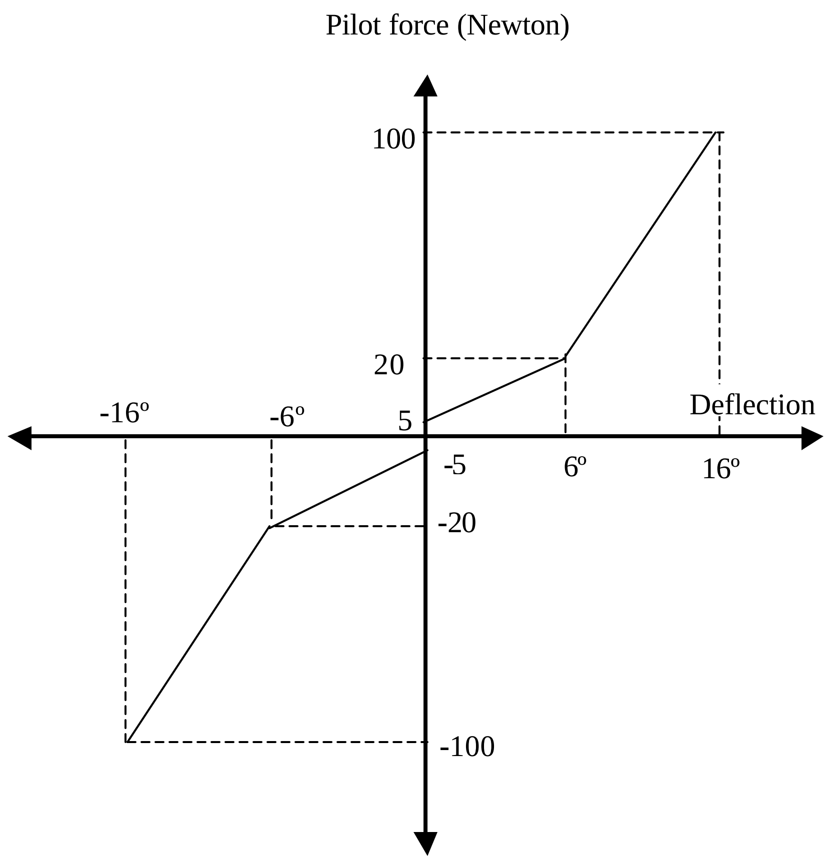


Figure 5: A320 Cockpit Instrumentation (See Figure 5a for actual instruments)

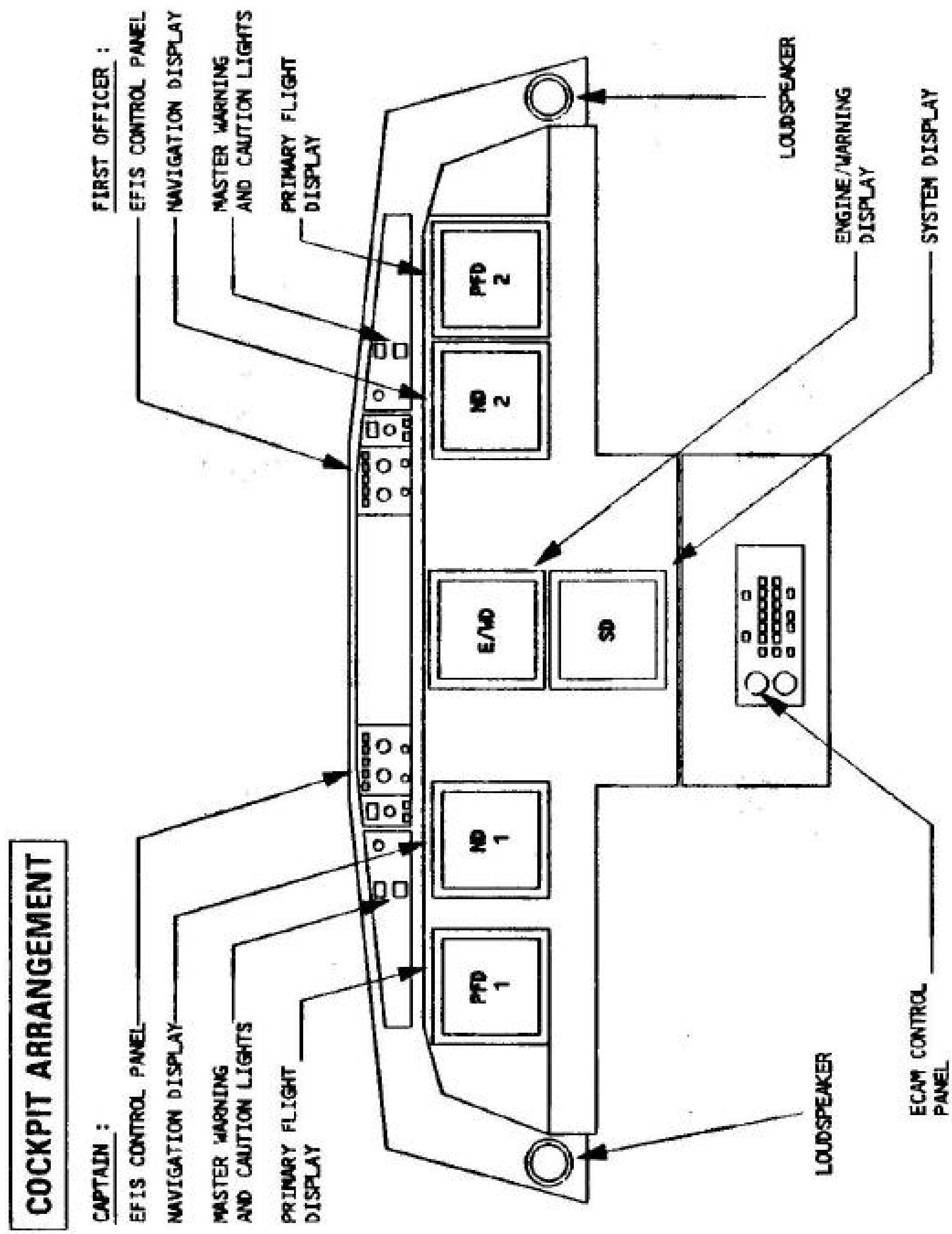


Figure 6: Primary Flight Display

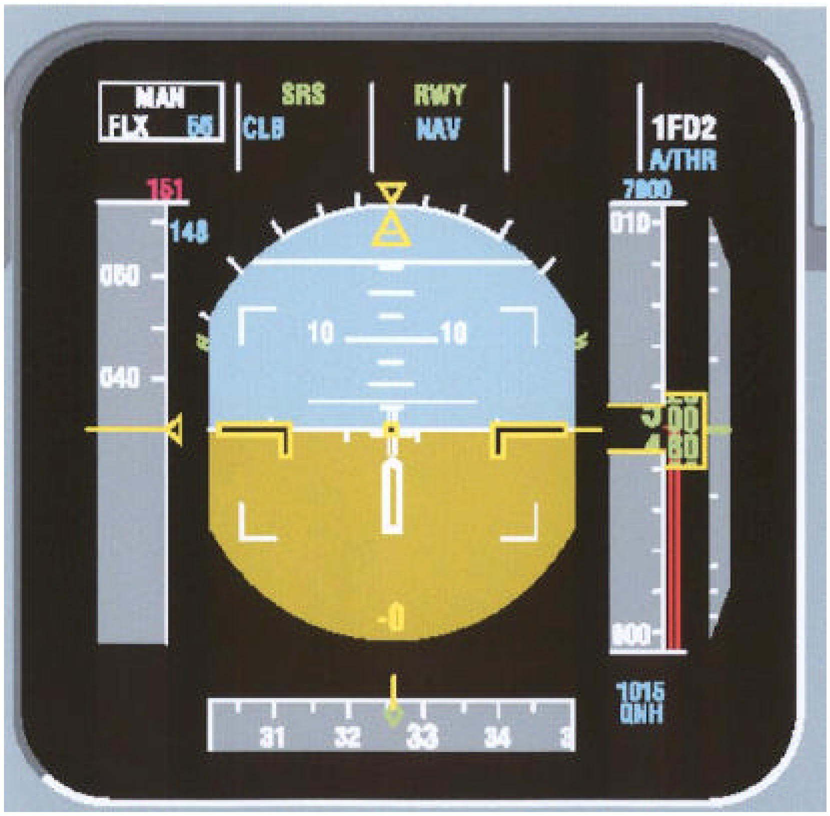
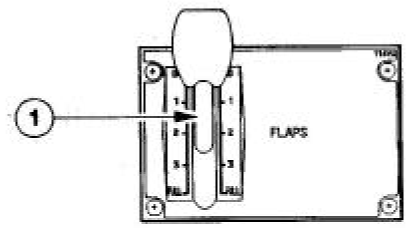


Figure 7: Slats/Flaps Configurations

A319/A320/A321 GULF AIR FLIGHT CREW OPERATING MANUAL	FLIGHT CONTROLS	1.27.50	P 5
	FLAPS AND SLATS	SEQ 005	REV 23

CONTROLS AND INDICATORS

PEDESTAL



(1) FLAPS lever

The FLAPS lever selects simultaneous operation of the slats and flaps.
The five lever positions correspond to the following surface positions :

Position	SLATS	FLAPS	Indications on ECAM			
0	0	0			CRUISE	HOLD
1	18	0	1			HOLD
		10	1 + F	TAKEOFF		
2	22	15	2	TAKEOFF		APPR
3	22	20	3	TAKEOFF	LDG	APPR
FULL	27	35	FULL		LDG	

Before selecting any position, the pilot must pull the lever out of the detent. Balks at positions 1 and 3 prevent the pilot from calling for excessive flap/slat travel with a single action.

Note : The pilot cannot select an intermediate lever position.

Takeoff in configuration 1 :
1 + F (18°/10°) is selected. If the pilot does not select configuration 0 after takeoff, the flaps retract automatically at 210 knots.

Takeoff or go-around in configuration 2 or 3 :
If the pilot selects configuration 1, he gets 1 + F (18°/10°) if airspeed is under 210 knots. If the pilot does not select configuration 0 after takeoff, the flaps retract automatically at 210 knots.

Configuration 0 to configuration 1 in flight :
Configuration 1 (18°/0°) is selected.

Note : After flap retraction, configuration 1 + F is no longer available until the airspeed is 100 knots or less, unless configuration 2, 3, or FULL has been selected previously.

Figure 8: Aerodrome Ground Movement Chart AD 2-11

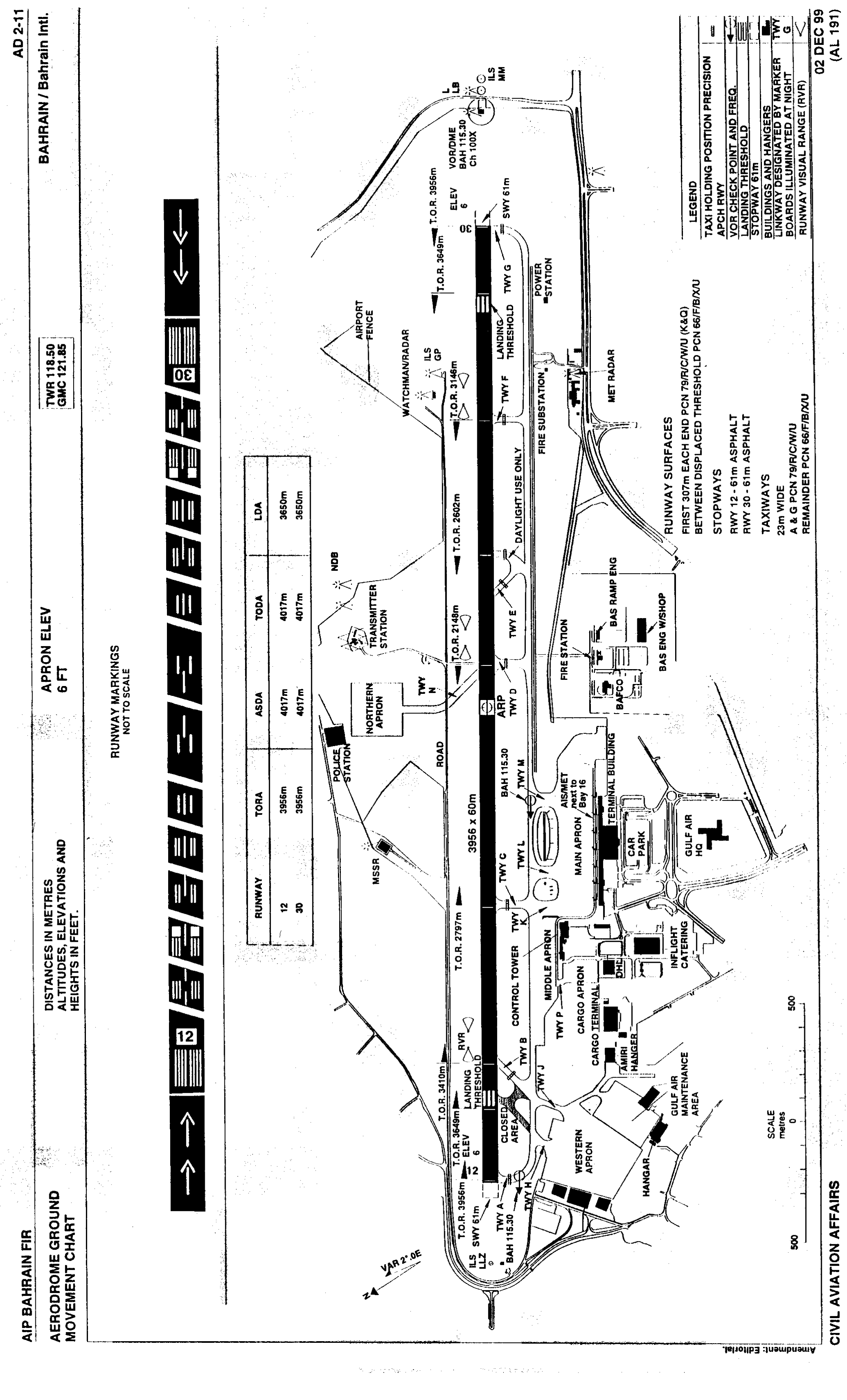


Figure 9: Aerodrome Lighting Chart AD 2-13.

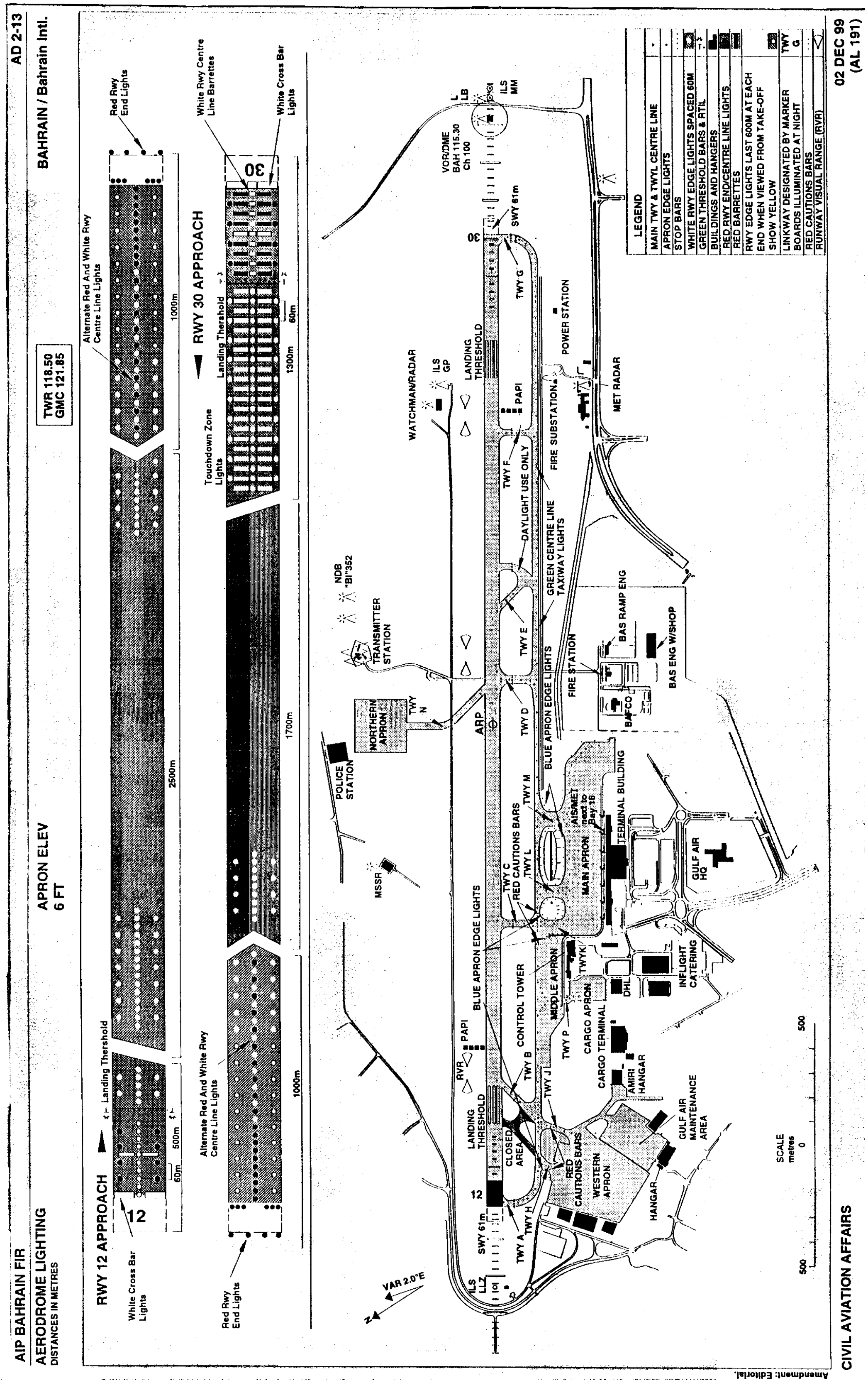


Figure 9: Aerodrome Lighting Chart AD 2-13.

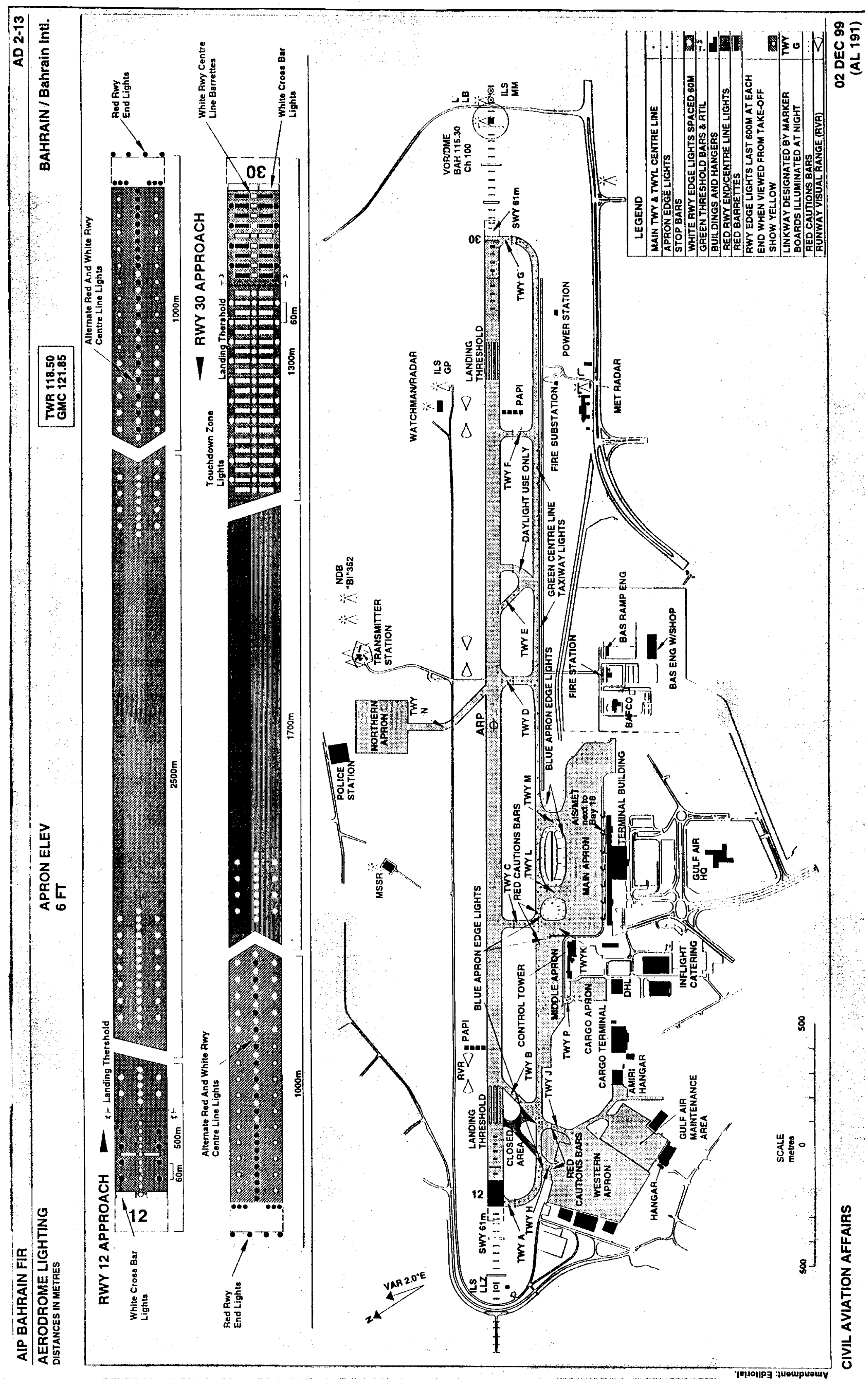


Table 1: Injury chart.

	Flight Crew	Cabin Crew	Passengers	Other	Total
Fatal	2	6	135	0	143
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	0	0	0	0	0
Total	**2**	**6**	**135**	**0**	**143**

Table 2: Flying and Duty Time - Captain

FLYING TIME	HOURS
Total Pilot Time	4,416
Total Pilot in Training sponsored by Gulf Air	186
Total Pilot with Gulf Air	4,230
Total Gulf Air A-320 PIC [15]	86
Total Gulf Air A-320 SIC [16]	997
Total Gulf Air B-767 SIC	2,346
Total Gulf Air L1011 SIC	800
Total Gulf Air Flight Engineer	2,402

The captain's flight and duty time according to Gulf Air records was as follows:

	DUTY TIME (Hrs:Mins)	FLIGHT TIME (Hrs:Mins)
Previous 24 hours	00:00	00:00
Previous 7 days	24:35	17:05
August 2000	61:40	25:35
Since 1 Jan 2000	1,073:17	475:35

Table 3: Flying and Duty Time – First Officer

FLYING TIME	HOURS
Total Pilot Time	608
Total Pilot in Training sponsored by Gulf Air	200
Total Pilot with Gulf Air	408
Total Gulf Air A-320 PIC	0
Total Gulf Air A-320 SIC	408
Total Gulf Air Flight Engineer	0

The first officer's flight and duty time according to Gulf Air records was as follows:

	DUTY TIME (Hrs:Mins)	FLIGHT TIME (Hrs:Mins)
Previous 24 hours	00:00	00:00
Previous 7 days	24:35	17:05
August 2000	123:30	72:03
Since 1 Jan 2000	1,170:43	408:33

Table 4: Flap Retraction Time

CONFIGURATION	FLAP POSITION (DEGREES)	FLAP RETRACTION TIME (SEC.)
full to 3	35 to 17[24]	4.6
3 to 2	17 to 15	2.4
3 to 1+F	17 to 10	3.9
2 to 1+F	15 to 10	2.5
1+F to 0	10 to 0	7.4
full to 0	35 to 0	13.2

Table 5: Weight and Balance

TAKEOFF WEIGHTS		
	POUNDS	**KILOGRAMS**
Basic Operating Weight	97,623	44,281
Ramp Fuel Weight	23,589	10,700
Passenger Weight	18,554	8,416 (61 male, 37 female, 29 children, and 8 infants for a total of 135 passengers)
Baggage Weight	11,325	5,137
Taxi Gross Weight	151,091	68,534
Maximum Taxi Weight	170,635	77,400
Takeoff Fuel Weight	23,149	10,500
Takeoff Gross Weight	150,651	68,334
Maximum Takeoff Gross Weight	169,754	77,000
TAKEOFF CENTRE-OF-GRAVITY AND SPEEDS		
Takeoff Centre of Gravity (CG)	32.7% mean aerodynamic chord (MAC)	
Takeoff CG Limits	15% to 37% MAC	
Takeoff Stabiliser Trim Setting	0.9 units airplane nose down (ND)	
Takeoff Flap Setting	1 + F	
Takeoff Speeds	V_1=154 knots, V_R=161 knots, V_2=161 knots	

Based upon the FDR data about the aircraft weights at the time of take-off and landing (impact), the fuel consumed during the flight was about 8,183 kilograms (18,003 pounds). Based on this fuel burn, the cg at the time of the approach would have been approximately 35.9% MAC, which is within the cg limits for the airplane.

ESTIMATED LANDING WEIGHTS		
	POUNDS	KILOGRAMS
Fuel Burn	18,003	8,183
Landing Gross Weight	132,524	60,238
Maximum Landing Gross Weight	142,198	64,500
Landing Speed	V_{APP}=136 knots	

Table 6: Radio Navigation and Landing Aids

Type of aid CAT of ILS/MLS/VAR	ID	Frequency	Hours of operation	Site of transmitting antenna coordinates	Elevation of DME transmitting antenna	Remarks
1	2	3	4	5	6	7
VOR/DME (2°E/1996)	BAH	115.300 MHZ	H24	261532.12N 0503915.39E	24FT	121°MAG 0.25 NM MAINT every TUE 0500 – 0800
L[30]	LB	395 MHZ	H24	261530.25N 0503918.62E		121° MAG 0.47NM FM THR RWY 30
LLZ RWY 30 ILS CAT 1	IBI	110.300 MHZ	H24	261656.34N 0503649.44E		301°MAG 2.18NM FM THR RWY 30 MAINT every MON, 0530 – 0800
GP[31] 30	Dots/ Dashes	335.000 MHZ	H24	261555.88N 0503845.47E		3.00°, RDH 55FT
ILS DME		1001 MHZ	H24	261555.88N 0503845.47E	42 FT	Co-located with GP Dist. Zero TDZ RWY 30
MM 30[32]	Dot/ Dash	75 KHZ	H24	261529.77N 0503919.45E		121°MAG 0.48 NM FM THR RWY 30

Table 7: Responses vs Altitudes Loss

Pitch-up Command	Response Time	Reaction Time	Altitude Loss
full-back stick[35]	1 second	0.25 seconds	300 feet
half-back stick	1 second	0.5 seconds	540 feet
half-back stick	2 seconds	1 second	670 feet

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

Distance from runway 12 threshold nm	Time LT	Height AGL ft	CAS knots	Flaps 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 [missed approach point]	1927:23				The captain asks the first officer "Tell him (ATC) to do (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'	