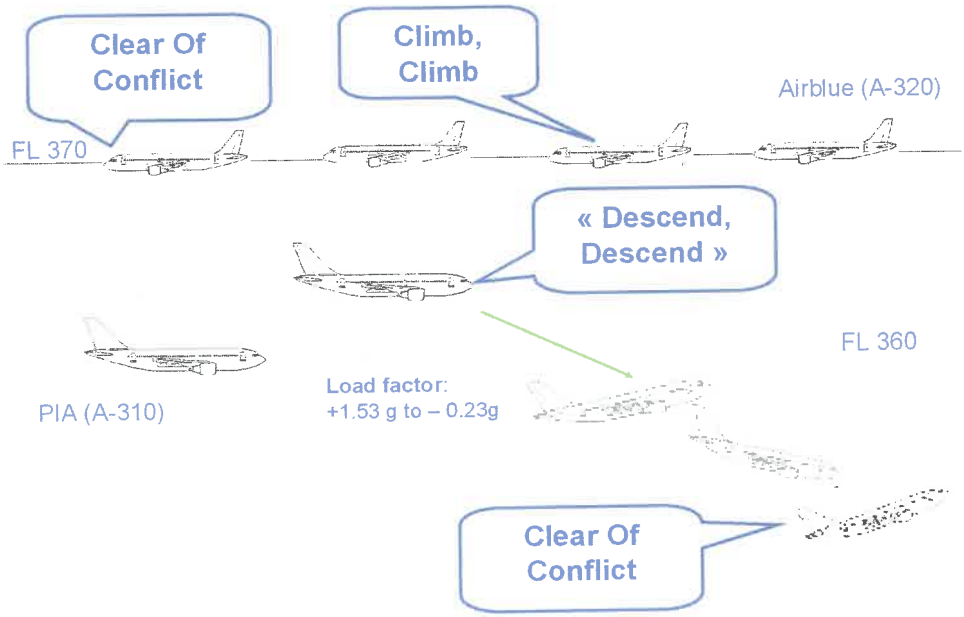
HQCAA/1901/294/SIB

AIRCRAFT INCIDENT INVESTIGATION REPORT
PAKISTAN CIVIL AVIATION AUTHORITY



TCAS-RA BETWEEN PIA A-310 & AIRBLUE A-320 ON 22 DECEMBER 2004

(Safety & Investigation Board)

FINAL REPORT

TCAS RA BETWEEN PIA 309 AND AIR BLUE 406 ON 22 DECEMBER 2004

Authority: Director General Civil Aviation Authority Memorandum HQCAA/1901/294 dated 24th December 2004. (Appendix 'A')

SYNOPSIS

On 22 Dec 2004, PIA flight 309, an Airbus 310, Reg. # AP-BGR was operating a scheduled flight from Islamabad to Karachi at an altitude of 36, 000 feet (Flight Level 360). En-route to Karachi, it crossed an Airbus 320 belonging to Air Blue, Reg. # AP-BGW, which was on a reciprocal track maintaining Flight Level 370 (37, 000 feet). While crossing, the two aircraft received Traffic Collision Avoidance System Resolution Advisories (TCAS RA). The advisory for Air Blue was **"CLIMB---CLIMB"** and for PIA was **"DESCEND DESCEND"** (Appendices A-1, A-2 and B).

The Air Blue claimed to have seen PK 309, therefore, did not act on RA. The PK-309 response to RA was impulsive which resulted in aircraft going into porpoise which resulted in injuries and panic in the passenger cabin. After 30 minutes, the Captain of PK-309 asked for ambulances and doctors to be available on landing. As a number of VIPs such as federal minister for information, chairman senate and an ex Chief Justice of Pakistan were on board the PIA aircraft; there were media reporters at Karachi airport who resorted to sensational reporting in the national press. The incident was also reported by international media and Airbus Industries offered its assistance for investigation.

However the two aircraft were never close enough to raise the question of a potential mid air collision. Both aircraft reported maintaining their respective flight levels to Karachi radar controller. Due to non availability of facilities in the country, SIB felt the need for assistance from Airbus Industries, France. The course of investigations included research and analysis of the TCAS scenarios to determine as to what caused the RA when aircraft were not on any collision course. The response of aircrew was another important area for investigations. It is concluded that TCAS- RA triggered due to faulty computation of Air Data Computer and injuries were caused due to incorrect response by PIA crew. The investigations have been delayed due to non cooperative and delaying attitude by Flight Operations PIAC.

PERSONNEL INFORMATION

Aircrew of Air Blue:

Pilot in Command: Captain Mohammad Khalid

Date of Birth	:	05.01.2956
Type of Licence held and No.	:	ATPL 927
Medical date with status	:	February 2006, Class ONE
Type Rating	:	A-320
Type Current	:	A-320
Flying Experience	:	A-320 (800:00hrs)
Grant Total	:	10600:00 hrs
Total in Command	:	6000:00 hrs
Total in command on the type accident/incident occurred	:	350 hrs
Where trained	:	Airbus Industry-Toulouse France
Date of Joining the Organization	:	February 23, 2004

Co Pilot Mohd Nadeem Zafar, First Officer

Date of Birth	:	20.11.1966
Type of Licence held and No.	:	ATPL 1153-A
Medical date with status	:	November 2005, Class ONE
Type Rating	:	A-320
Type Current	:	A-320
Assist/Flight instructor Rating	:	CFI
Flying Experience	:	A-320 (338:00 hrs)
Grant Total	:	2813:00 hrs
Total in Command	:	2000:00 hrs
Where trained	:	Airbus Industry-Toulouse France
Date of Joining the Organization	:	March 29, 2004

Aircrew of PIAC Captain Mohsin Raza Rizvi (Pilot Not Flying)

Date of Birth	:	05-12-1995
Type of Licence held and No.	:	ATPL 655
Medical date with status	:	24-08-2005
Rating	:	PI
Type(s) held	:	B747, A300,A310, B707, B737, F-27
Type Current	:	A310
Assist/Flight instructor Rating	:	NIL
Check rating	:	DCP "TYPE A"
Flying Experience (Grant Total)	:	12170 Hours (22-12-2004)
Total in Command	:	5382 Hours (22-12-2004)
Total in command on the type	:	3071 Hours
Where trained	:	Amman, Jordan
Date of Joining the Organization	:	19-09-1978

Captain Anwer Khurshid Zaidi, Pilot Flying

Date of Birth	:	04-02-1958
Type of Licence held and No.	:	ATPL 633
Medical date with status	:	27-06-2005 (FIT)
Rating	:	PI
Type(s) held	:	B747, A300, A310, B707, F27, DCH6
Type Current	:	A310
Assist/Flight instructor Rating	:	Nil
Check rating	:	DCP "TYPE A"
Flying Experience (Grant Total)	:	13544 Hours (22-12-2004)
Total in Command	:	9065 Hours (22-12-2004)
Total in command on the type	:	3612 Hours
Where trained	:	Jordan, Amman
Date of Joining the Organization	:	06-02-1978

1 FACTUAL INFORMATION

1.1 RVSM Airspace

Owing to the growing air traffic within same air corridors a need was felt to reduce the vertical separation between reciprocal aircraft from 2000 feet to 1000 feet so that the traffic can be managed efficiently by air traffic controllers. This reduction in vertical separation for aircraft flying in a particular corridor was implemented by Pakistan in November, 2003 as an ICAO requirement. Such an airspace, where the reduced vertical separation is implemented, is known as RVSM **(Reduced Vertical Separation Minimum)** airspace and the traffic complying with this requirement is called RVSM traffic.

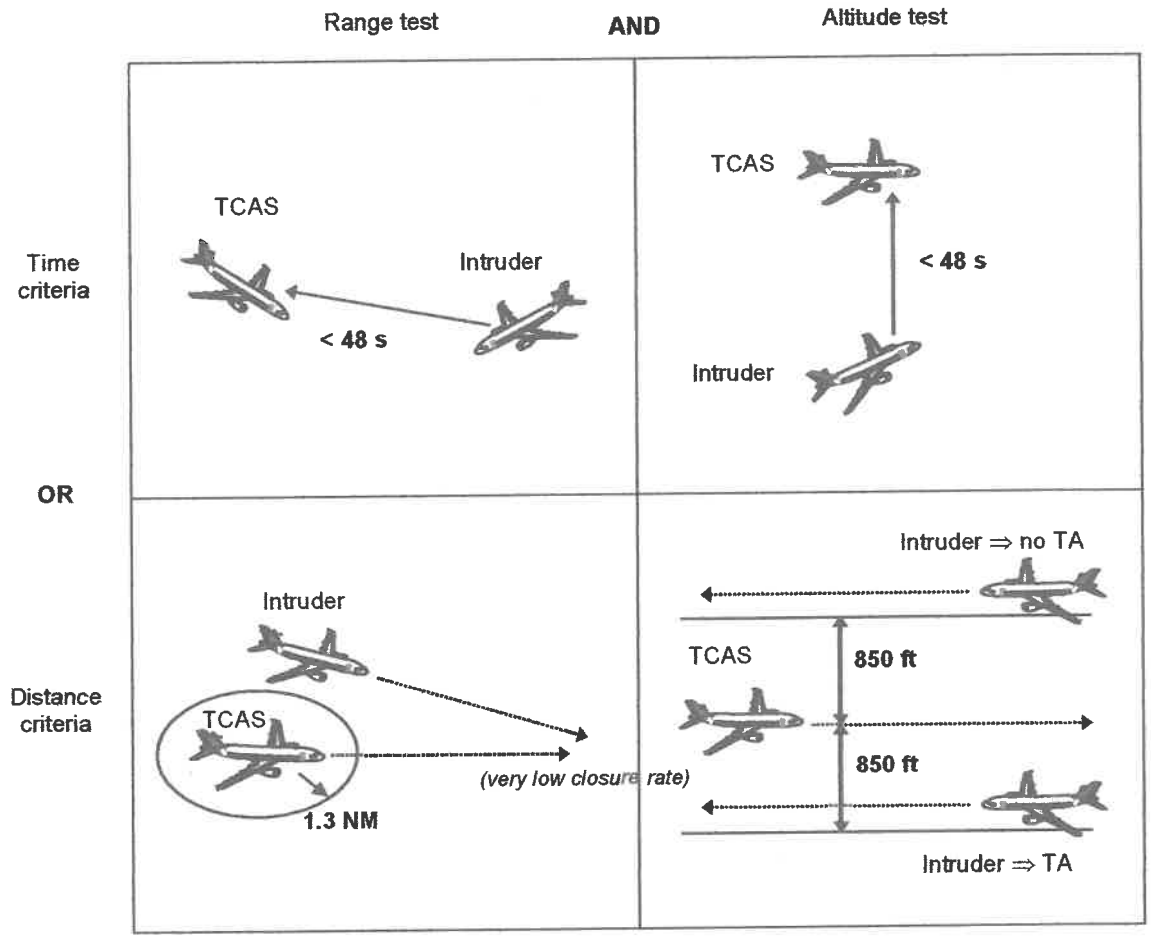
1.2 **TCAS Equipment** Aircraft operating in RVSM air space are required to have a Traffic Alert and Collision Avoidance System installed on aircraft, besides having a transponder, which transmits the aircraft position and its altitude and interrogates the same from intruding aircraft. This transmission is also picked up by the radar, which keeps track of the air traffic in its designated control zone. The TCAS works on the principle of the rate of closure between any two aircraft. If two TCAS equipped aircraft are likely to converge, the TCAS would give an initial warning of a Traffic Alert (TA) to the aircraft. If, however, there is an imminent danger of a closure to less than 600 feet (closest point of Approach CPA) between two aircraft, as sensed by the TCAS computer, it will sound a warning called the Resolution Advisory (RA). The instructions to the pilots on receiving an RA command are that they should take smooth and prompt action as per the TCAS RA command. The TCAS RA commands over rules any other instructions that might be given to the pilot for resolving the traffic conflict.

1.3 **Principles of TCAS operations in RVSM** TCAS II triggers an advisory when **a range test and an altitude test are both satisfied**. These tests are performed on each altitude-reporting target, every second.

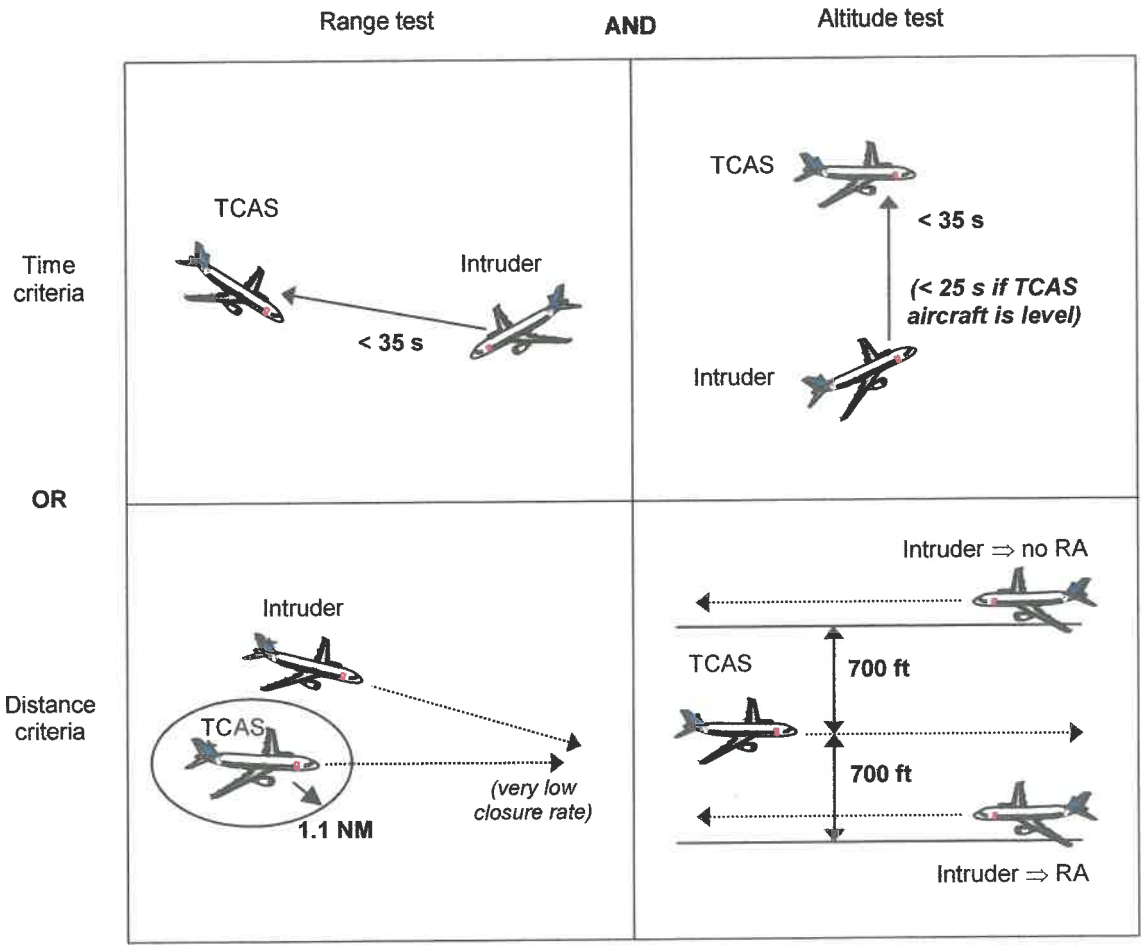
1.3.1 The principle of the **range test** is to compute the time-to-go to the CPA by dividing the distance between aircraft by the closure rate. The range test is satisfied if this time is lower than a threshold value (i.e., 48 s for TAs and 35 s for RAs). To address the specific case of very low closure rates, a protection distance has been introduced to avoid an intruder coming very close in range without triggering any

advisories. For this type of encounter, the range test is satisfied if the distance between aircraft is lower than this protection distance, (i.e., 1.3 NM for TAs and 1.1 NM for RAs). The principle of the **altitude test** is to compute the time to reach co-altitude by dividing the relative altitude between aircraft by the relative vertical speed. The altitude test is satisfied if this time is lower than a threshold value(i.e., 48 s for TAs and 35 s for RAs). If the own aircraft is level, the time threshold value for RAs is reduced to 25 s in order to detect a possible level-off manoeuvre of the intruder and thus to avoid the triggering of the RA.

1.3.2. To address the specific case of level aircraft or aircraft with a very low relative vertical speed, the altitude test is satisfied if the relative altitude between aircraft is lower than a fixed vertical distance threshold (i.e., 850 ft for TAs and 700 ft for RAs). The following figures illustrate the range and the altitude tests, with the associated threshold values for the altitude band including the RVSM airspace.

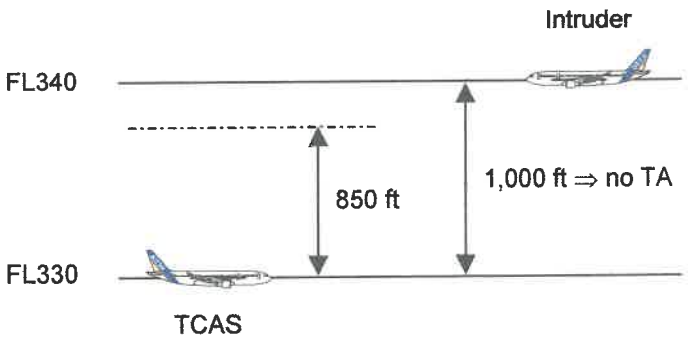


TA triggering by TCAS II version 7.0 in RVSM airspace



RA triggering by TCAS II version 7.0 in RVSM airspace

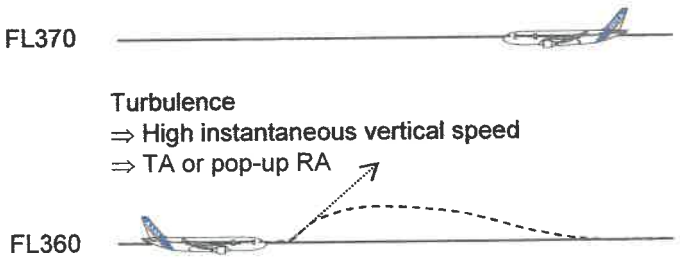
1.3.4. CAS logic behaviour for an encounter with a standard vertical separation. These encounters involve level aircraft at adjacent flight levels separated by 1000 ft. Figure below illustrates this standard type of encounter for TCAS II version 7.0.



Standard RVSM vertical separation

1.3.5. **Explanation for TCAS II version 7.0** In case of level aircraft, the altitude test is performed by the comparison of the relative altitude between the aircraft with an altitude threshold. If the relative altitude is lower than this threshold, the altitude test is satisfied and an advisory is triggered. The altitude threshold values for TCAS II version 7.0 are 850 ft for TAs and 700 ft for RAs. It means that when both aircraft are level at adjacent flight levels, the altitude test is not satisfied and therefore neither a TA nor an RA will be triggered.

1.3.6. **TCAS logic behaviour for an encounter with a standard vertical separation and turbulences.** These encounters involve an aircraft experiencing an atmospheric or a vortex turbulence that makes it deviate very suddenly with a high instantaneous vertical speed and an important acceleration towards another aircraft on an adjacent flight level. As a consequence there is a high vertical convergence and pop-up RAs can be triggered on-board both aircraft. Figure below illustrates this type of encounter in which the lower aircraft experiences a turbulence that makes it suddenly climb towards the other aircraft.



Turbulence

1.3.7. **Explanation for TCAS II version 7.0**

TCAS II is provided every second with the altitude of the own aircraft, from which it computes a vertical speed. If the aircraft experiences severe turbulence that makes it deviate very suddenly towards another aircraft, the altitude varies with an important acceleration. Therefore, TCAS II computes a high vertical speed. Therefore when it performs the altitude test with this high vertical speed, the time to reach co-altitude is lower than the time threshold. The altitude test is thus satisfied and an advisory is triggered.

1.3.8. Depending on the acceleration during the altitude variation, the time to co-altitude can become suddenly lower than the time thresholds for both TAs and RAs. In this case, a pop-up RA (i.e. no preliminary TA) is triggered. If it is only lower than the time threshold for TAs, then a TA is triggered.

1.3.9. The behaviour of the level aircraft TCAS II is similar. It receives the altitude of the intruder every second. When it detects the sudden altitude variation, it computes a high vertical speed for this intruder. Due to this high vertical convergence, the altitude test can be then satisfied and an advisory is triggered. Depending on the severity of the turbulence, either a TA or a pop-up RA can be triggered.

1.3.10. For instance, a level aircraft at FL360 is experiencing severe turbulence. Suddenly, its altitude varies so as its TCAS II computes a rate of climb of 2,200 fpm. If there is another aircraft at FL370, the time to reach this altitude with the computed vertical speed is 27 s. This value is lower than the time threshold for TAs (i.e. 48 s) and for RAs (i.e. 35 s). Therefore a pop-up RA (either an "Adjust Vertical Speed" or a "Descend") is triggered. Supposing that the other aircraft has a perfectly symmetrical view (this is an approximation because of the altitude report quantization), the time to co-altitude is also lower than the time threshold for TAs (i.e. 48 s). However it is greater than the one for RAs (i.e. 25 s) because of the reduced time threshold for level aircraft (cf. paragraph 3.1.2). Therefore only a TA is triggered for the level aircraft.

Technical History

1.4.1 **Performance of TCAS Equipment (PIA A-310)** The technical status of AP-BGR from the date of incident to 3/1/2005 was monitored During this period, following components were removed from the aircraft on pilot defect reporting. However these were declared serviceable during shop checks.

Component name/removal date	Part No/ Serial No	Reason for removal	Status after shop check
Digital Altimeter 23/12/2004	65205-230-4/ 1727	Pilot reported that ALT#2 under reads by 40 FT at 35000ft	Tested Found Serviceable
Digital Altimeter 25/12/2004	65205-230-4/S.No 2006	Alt #1 flickers by ± 290 Ft and also flag appears	Tested Found Serviceable

In addition to digital altimeters, a number of ADCs, which provide inputs to TCAS were removed on aircrew reports but declared serviceable during shop check. However during shop checks some bites were found registered which is an indication of malfunction of another component. See Appendix G-9

1.4.2 **Maintenance of Altimeters** CAA regulations make it mandatory for airline operators to check the serviceability and reliability of all altimeters installed in the RVSM certified aircraft. It was found that airlines are checking performance of altimeters every 15 days and their readings are duly recorded to ensure their reliability at all times during flight. **(Appendix G- 9)**

1.4.3 **Performance of Altimeters** Technical records of altimeters installed on AP-BGR were checked for last 30 days. During this period, the crew checked and compared the three altimeters on three occasions, the results are given here:

Date	**Alt #1**	**Alt # 2**	**Std By Alt**	**Difference between No. 1 & No. 2 Altimeters**	**Tolerance** (Ref. SB A310-34-212)
25/11/04	35000	34900	--	100'	160'
04/12/04	36000	35920	36000	80'	165'
18/12/04	35980	35880	36010	100'	160'

1.5 The average difference between the F/O and Capt's altimeters is found to be in accordance with the tolerances given by the Airbus vide SB No. A310-34-2112 Revision No. 34-Jan 30/02.

1.6 After the incident on 22 December 2004, this aircraft was scheduled on a flight to Kuwait from Karachi. On its flight from Karachi to Kuwait, the crew reported oscillation of No. 1 Altimeter from 34000 to 34300 ft. In view of this altimeter oscillation the Flight Crew requested for a change from RVSM to Non RVSM clearance to Kuwait. The system was checked at Kuwait, which was found satisfactory. On the technical report made in Kuwait, the crew was requested to monitor the system on the next flight. It was checked again by the crew during flight from

Kuwait to Karachi. The results shown below were within limits. (See **Appendix "G-1")**

Date	Alt #1	Alt # 2	Std By	Difference between No. 1 & No. 2 Altimeters	Tolerance
23/12/04 In Air	35000	34920	35000	80'	160
23/12/04 On Ground	50'	50'	90'	0	50 ft

The performance of altimeters was further monitored for next 30 days. The monitoring did not reveal any defect with Altimeters.

1.7 **RVSM certification** A- 310 of PIAC and A -320 of Air Blue were found RVSM certified. See Appendix G-10

1.8 **Pilot Reported Defects and Rectification (A 310- PK 309)**

Aircraft defect history of pilot reported defects revealed that aircrew on 30 November 2004 reported a defect "**ADC Failure Light Came On".** The Air Data Computer S NO 91501966 was replaced with 93071647. **(Appendix G-2)**. The fleet defect history on (PALMIST) records the following entry

"ADC #1 REPLACED BITE TEST OF ADC # 1
C/O FOUND SAT ADS TEST C/O FOUND SAT"

The removed ADC was later checked in the shop and was declared serviceable with a note:-**"Reported Defect Not confirmed Tested Found Serviceable However Found Bite Code = 010001 (A O A Sensor #1).** (Appendix G-4) It means that angle of attack sensor # 1 has some problem and that was registered by ADC during flight. This ADC was last removed from A/C AP BGO on 24-08-04 due to its intermittent ON/OFF problem.

1.9 **Angle of Attack Sensor** The defective angle of attack sensor remained installed on AP BGR till the near miss occurrence. However a Technical Service Requirement (TSR) attached as **appendix " G 5** " was raised by Technical Service on 13-12-05 for removal of defective AOA sensor # 1. The defective AOA Sensor #1 S No 01177 was replaced by # 00456 on 27 12 05 after the incident. During

shop check its all three resolvers were found out of tolerance (1&3 +3 Deg out and #2 = 7Deg out. The component's previous history is attached as appendices G 6 & G-7.

1.10 **A-320 Aircraft AP-BGW (ABQ406)** Technical records from (22/11/2004 TO 22/12/2004) of AP-BGW were checked and there was no reported fault regarding Altimeter system or TCAS.

1.11 **TECHNICAL STATUS OF AP-BGW AFTER THE INCIDENT** The aircraft was monitored after the incident for six months. There has been no defect reported for ADC and TCAS.

Flight Recorders

1.12 **ATC Tape extracts** The communication between aircrew (PIA and Air Blue) with ATC on frequency 125.4 MHZ for22nd December 2004 is reproduced in Appendix "C". Salient aspects are as follows:

a. The event is announced by PIA crew after flying past ABQ, 406(Air Blue). PIA 309 reported activation of TCAS RA, which commanded a descend due to conflicting reciprocal traffic. At this point in time the radar controller informed PIA 309 that there was no traffic other than ABQ 406, which was maintaining FL 370 as per the radar video display.

b. PIA 309 contested the height of ABQ 406 to be below FL 370; while the radar controller reconfirms that no level variation was observed in the case of ABQ 406.

c. The PIA announced that they were descending due to RA activation

d. ABQ 406 also confirmed the TCAS activation

e. ACC announced that both the traffic were maintaining their assigned levels of FL 360 and FL 370 and it could not find any change in the level.

f. At 2040 hours i.e. 25 minutes after the TCAS event known to only Radar at that time. (LT) PIA 309 requested air traffic control to arrange for ambulance

and doctors for injured passengers. The cause of injuries to the passengers was not reported to the controller at any stage of the flight.

g. PIA 309 landed at Karachi at 2105 hours (LT).

1.13 Radar Picture

1.13.1 In the area of the incident the coverage of Radar is secondary i.e. Transponder based. The radar has an RPM of 10 i.e. the aircraft is displayed with 06 second interval. The altitude ambiguity is ± 50 ft, and aircraft is shown at nearest hundredth of feet in first three digits of hundreds/thousands of feet. Along the aircraft blip the aircraft call sign, ground speed, altitude and climb/descent is indicated. Both incident aircraft were displayed 100% at Karachi ACC and incident flights' parameters were recorded. Initial Report analyses were based on Radar recording. Following are the flight parameters of two aircraft:-

Range and Altitude Tests for TCAS RA.

1.14 The two aircraft had range closure rate of 970 Kts. The projected time of 35 seconds to CPA is therefore about 9 nm. As Air Blue was at correct altitude and as per DFDR only PK-309 climbed, therefore, RA for this scenario would have generated in 25 sec to CPA, which is about 6.5 nm at these speeds/closure rate. The synchronization of ATC Tape extracts with radar picture and then PK-309 calls on DFDR extracts indicate that RA action was executed when lateral separation between two aircrafts was less than 6 nm. It is therefore concluded that TCAS-RA was generated as per system design when Range Test and Altitude Test were satisfied in the area of the incident.

1.15 **The coverage of Radar.** The radar recording of Karachi radar and Lahore are attached as appendix "D" and is also given in Appendix "E" with time progression. The salient observations are:-

a. Air Blue ABQ 406 got airborne from Karachi at 1921 hours local time (LT) and was cleared to climb and maintain Flight Level (FL) 370 (thirty seven thousand feet).

b. It maintained FL 370 throughout its flight in Karachi flight information region. No variation was observed and the aircraft also did not report any deviation from its assigned level.

c. PIA 309 passed MOLTA (abeam Multan position) at 1957 hours (LT) and reported maintaining FL 360 (thirty six thousand feet). The radar picture, however, showed the aircraft at FL 361 (thirty six thousand one hundred feet – within the acceptable limits).

d. The radar video indicates that PIA 309 changed to FL 362 (thirty six thousand two hundred feet) once at approximately 100 nautical miles from Rahim Yar Khan and there after remained steady at FL 361.

e. The radar video does not indicate any variation in the levels of PIA 309 (FL 361) and Air Blue ABQ 406 (FL 370) until the crossing of these two aircraft.

f. The radar picture confirms the altitude variations of PIA 309 i.e. from 361 to 362, then descending to FL 361 and from FL 361 to 363.

g. The aircraft altitude reduced to FL 361 after assessed RA point and 35 seconds before announcement of the incident. At assessed RA point when altitude is down to FL 361 the lateral distance between two aircraft is about 06nm.

h. Variations in the altitude of PIA 309 were also evident on the radar picture when it crossed PIA 370, which was following ABQ 406. Where it climbs to 361, 362 and 363. It then descended to 360.

i. The Lahore radar shows that PK-309 initially maintained FL-360, and then climbed to FL 361 at 93 NM from Molta, and then FL 363 at 50 NM from Molta.

1.15 Digital Flight Data Recorders

1.15.1 **DFDR of A320 Air Blue** The DFDR of Air Blue was down loaded by Airbus Industries. Following factual information was revealed:

a. Initial conditions are normal for cruise (figures 6.1 to 6.3 Appendix G-12)

b. AP 1 is engaged in ALT / NAV modes.

c. ATHR is engaged and active (speed mode).

d. ALT remains stable at 37000ft with ground speed was 530 kts and track 041°.

e. Heading is $043^{0.}$

f. Mach number is 0.79.

g. There is no roll or pitch activity.

h. On TCAS-RA no avoidance action is operated by the A 320, the altitude and attitude remains stable.

i. The A320 was equipped with a TCAS II version 7.0.

j. The recorded TCAS message shows TA for one second and RA for 10 seconds followed by TA for eight seconds.

k. The computation of a RA (resolution advisory – real collision threat) during 10 seconds (1 data is recorded each second), in association with an"up advisory" and an "up advisory corrective".

l. Then, the "up advisory" is cancelled and the TA (traffic advisory – potential collision threat) is computed during approximately 8 seconds, in association with a "clear of conflict" for 1 second

1.15.2 **DFDR of A310 PIA** It was retrieved in Microsoft Excel Sheet form by PIA and is attached as Appendix "F" The DFDR data at a later stage was handed over to Airbus Industries, Toulouse, France. The analysis at SIB revealed that:

a. The aircraft maintained about 150 feet above FL 360 from 25 minutes before the incident until three minutes before the incident.

b. About three minutes before AP disengagement the climb increases from 36154 feet to 36240 feet in 24 seconds and then back to 36150 feet.

c. About 07 seconds before AP disengagement aircraft climb to 36242 feet from 36162 feet in 06 seconds.

d. Maximum rate of climb is 21 feet / sec registered 3 - 4 sec before Auto Pilot disengagement.

e. On both climb occasions the speed also increased by 2 – 3 kts.

f. During both climbs and speed increases no inputs to aircraft and engine control were given by the pilots i.e. engine RPM. Elevator Deflection, Control Column deflection and vertical acceleration remained constant.

g. Altitudes recorded A-310 is maintaining a flight level 36150 feet till 15:06:02. It then shows a gradual climb of 30 feet in next 24 seconds i.e. its altitude is 36183 at 15:06:2. Latter it indicates a level variation every second from 36183 to 36204, 36225 and 36240.

h. Changes in Upwards Vertical Speed In three seconds A-310 when at a relative altitude of 817 feet from Air Blue 320, has shown a rate of climb 0f 21 feet per second, 21 feet per second and 15 feet per second respectively for three seconds.

i. Pitch Angle Changes The AP is disengaged at 15:06:32, within next three seconds the pitch of A310 shows a sudden change from +ve 1.4 to –ve 1.4 For next 30 seconds the pitch is changing abruptly from +1 to .5 to 1.5 to -0.2 to 1.6 to 0.7 and then 1 in 14 sec.

j. Vertical Accelerations The vertical accelerations on all three accelerometers also show changes from 1.191 to minus 0.2, 1.438 to minus 0.145 and so on.

k. Disengagement of Auto pilot The auto pilot #2 is disengaged at 15:06:30 at an altitude of 26242 feet. The auto pilot is re-engaged after 18 seconds at an altitude of 36158 feet.

l. Within 2 seconds of AP disengagement Gs are reduced from +1 to +.5 and then to +1.5 in 3 seconds; and again to -0.2 in 03 seconds and +1.6 in two seconds. In 08 seconds aircraft was subjected to more than +1.6G change twice.

m. Changes of engine RPMs to 48% from 75% and throttle lever angles is simultaneous with AP-1 disengagement.

1.15.3 **Factual description of DFDR data By Airbus Industries, France.**

a. A310 **has a** recording limitation; hence it does not record any up or down advisory because the TCAS data are not properly treated by the acquisition part (DFDAMU). In fact some DFDAMU Part Number on A310 aircraft does not acquire/record the TCAS parameter (Label 270) due to ARINC-label interface mismatch. As this aircraft is fitted with this DFDAMU, no TCAS information is available (Figures 4.4 and 5.1 Appendix G 11).

b. The TCAS data are additional recommended parameters, not mandatory.

c. An offset between the AOAI and AOA2 of $+2.5^{o}$ approximately is noticed. At time 15.06.43 the AOA1 is recorded above 10^{0} (clean configuration) and the stall warning is activated as per design (Figure 4.1 Appendix G-11).

d. The PTWS (pitch trim wheel synchro) remains at o. The parameter is considered as not valid (Figure 4.1).

e. An offset is seen on the lateral load factor of approximately 0.014g.

f. AP2 is engaged in Profile Speed and NAV modes.

g. ATHR is engaged.

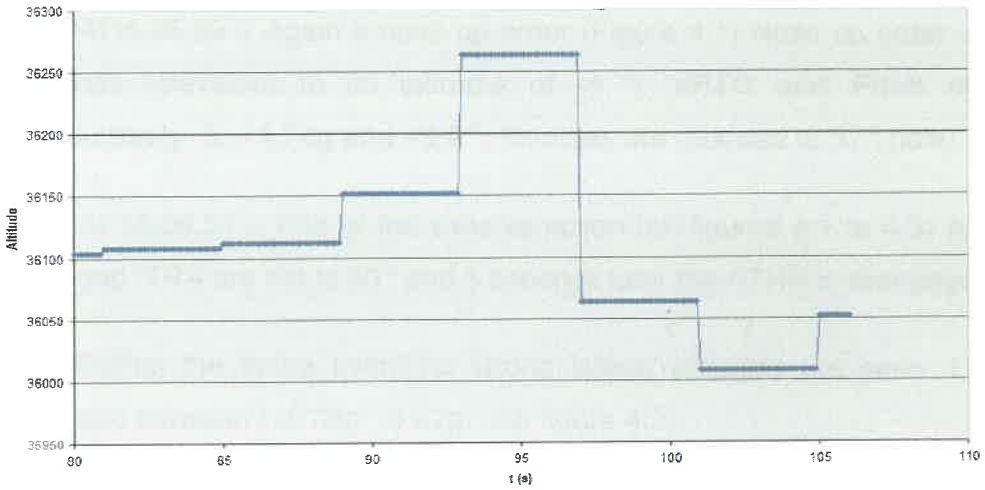
h. ALT is 36000ft.

i. Heading is 232°.

j. Pitch is 1.5°, no roll activity.

k. Mach is 0.81.

l. Chronological evolution of the situation according to recorded time:15:06:24. The aircraft speed and altitude start slightly to increase. Around 15.06.29, TAOA1 increases to +6.5° and the barometric altitude (ALT) increases to a maximum of 36260FT.



m. At this time the recorded elevators, pitch and VRTG value are constant.

n. Before and after the event some repetitive AOA1 jumps (cf. figures 4.5 and 4.6 Appendix G 11) are noticed. The recorded barometric altitude ALT comes from ADC1. ALT is corrected from AOA1.

o. At 15.06.32 – Evasive action (figures 4.1 and 4.2 Appendix G-11) AP2 is disengaged and nose down order is applied (elevator to +1.5°). The throttles are retarded from 62 ° to 45 °, which leads to ATHR disengagement and EPR decreasing value from 1.22 to 0.8.

p. The elevators movement (+ 1.5 °) is linked to a force of approximately 5 daN applied on the Control Column. There is an AP "automatic" disconnection when the amount of force applied on the control column is above 15 daN.

q. At 15.06.33 – Pitch decreases (Figure 4.1) Pitch starts to decrease and reaches - 1 ° in 2 seconds. VRTG decreases to +0.49g.

r. At 15.06.34 – Nose up order (Figure 4.1) Nose up order elevators to an extreme of +4 °) is applied. **VRTG and pitch decrease respectively to -0.23g and -3.5 °.** Altitude is recorded at approximately 36000ft.

s. The parameters show that the ALPHA TRIM law is active, 2 successive nose up movement of the stabilizer from -1 ° to -0.5 ° are recorded (stabilizer, according to ALPHA TRIM law, reacts as per design). In fact the FAC computes AOA voted that is the middle of the 3 AOA. If (AOAx – AOA voted) 3.6 ° for more than 450ms, then AOAx is forced to 0 for the rest of the flight.

t. At15.06.39 – Again a nose up order (Figure 4.1) Nose up order during 9 seconds (elevators to an extreme of -4 °). **VRTG and Pitch increase respectively to +1.74g and +9.9 °.** Throttles are retarded to 37 ° (idle).

u. At 15.06.51 – End of the evasive action (cf. figures 4.1 to 4.3) AP is re-engaged. TRA are set to 60 ° and 3 seconds later the ATHR is reengaged.

v. During the entire event no strong lateral activities are seen, LATG is recorded between (+0.05g -0.02g); (cf. figure 4.2).

1.16 Injuries to personnel

1.16.1 **Cabin Crew Personnel** Six personnel from cabin crew were referred to Agha Khan University Hospital (AKUH), for medical treatment and out of them only two were detained for observation and necessary investigations. Of the two cabin crew personnel kept under observation at AKUH only one was advised medical leave and was subjected to further clearance. The details can be seen at Appendix "H"

1.16.2 **Passengers** Two passengers with minor injuries were evacuated to AKUH for treatment.

1.17 **Damage to Aircraft** There was no damage to either of the aircraft.

1.18 **Meteorological Information** The weather was fine and visibility was not a factor as per aircrew and ATC evidence.

1.19 **Flight Conditions:** According to the pilots the weather and the visibility were fine.

1.20 **Preservation of Cockpit Voice recorders:** CVR of both the aircraft were not preserved as both aircraft were in the middle of their journeys.

1.21 **Evidence Collected From Witness Interviews**

1.21.1 Facts collected from various witnesses interviewed are summarised:

Witness No. 1 Pilot Not Flying (PNF Occupying Right hand seat)

a. Evasive action was taken by disconnecting the Autopilot and going down.

b. The other A/C first appeared at 800 feet on TCAS, when RA came it was 700 feet.

c. PNF informed ATC controller.

d. It took 2 to 3 minutes for settling after evasive action.

e. Senior Purser inquired from PNF as to what had happened?

f. PNF informed the senior purser that an RA was received.

g. Senior Parser informed him about the injuries in the passenger cabin.

h. PNF requested for a doctor and assistance at the Karachi airport 30 minutes after of occurrence.(see Appendix 'C')

i. The Cockpit Voice Recorder (CVR) was not preserved.

j. The weather and visibility were fine.

k. The role of ATC was positive.

l. At the time of occurrence Auto Pilot 2 was engaged and NO 1 transponder was reporting altitude.

m. The altimeters were serviceable and there was no anomaly.

PNF's incorrect understanding

i. If the rate of closure is slow then the Traffic Advisory comes at + or -700 feet and Resolution Advisory comes at + or – 400 feet.

ii. PNF is also of the view that during an RA activation the maximum reaction time to avoid a conflict is 5 seconds. PNF further states that they had been trained to take evasive action abruptly and promptly.

iii. The evasive action for descend would create – Gs, causing injuries and bad feelings amongst the crew and passengers.

iv. PNF insists that the reaction time is always 5 seconds in which corrective action has to be completed and if there is a change in RA then the action has to be completed within 2 ½ seconds.

v. According to PNF, PF took evasive action of descend and that had to be abrupt.

1.21.2 **Witness No 2 Pilot Flying (PF Occupying Left Hand Seat)**

a. He did not notice ant technical problem with the aircraft.

b. He used # 2 Auto pilot as per captain Mohsin's instructions.

c. ATC transponder No 1 and Altimeter NO 1 were selected.

d. No abnormality on altitude reporting was observed.

e. He did not receive any TA rather a direct RA was received.

f. He disengaged the auto pilot and manually applied controls to descend the aircraft.

g. He was not visual with Air Blue.

h. He on receiving a "Traffic" call from TCAS aural warning system saw indication of 800 followed by RA.

i. He was not visual with any other a/c after Air Blue on his route to Karachi.

j. Entry of a number of passengers including VIPs into the cockpit, after the incident, caused undue impediment in accomplishing the tasks expected of aircrew in a post incident scenario.

k. VIPs came one after the other to the cockpit and inquired as to what had happened.

l. PF politely satisfied them.

m. Flight purser informed him about the panic, injuries and noise in the passenger cabin.

n. The normal passengers behaved well.

o. He explains that the evasive action was steeper and tougher because the Air Blue did not take any evasive action of CLIMB.

p. He and his family had been disturbed due to false and maligning media reporting.

1.21.3 **Witness No. 3 (PF Air Blue Flight 406).**

a. He had visual contact with PK 309

b. The separation decreased from 900 to 800.

c. While crossing he received RA for "Climb Climb" followed by "Clear of Conflict".

d. By the time he could have been in a position to take action for climb, the conflict was clear.

e. Radar confirmed our level as 370.

f. After 6 minutes it crossed another aircraft maintaining 1000 feet separation.

1.21.4 **Witness No. 4 AREA RADAR CONTROLLER (N)**

a. On 22nd December 2004, duty time 1500 to 2200 LT.

b. PK 309 OPRN/OPKC F 361 reported TCAS at 1509 UTC or 2009 LT.

c. ABQ 406 OPKC/OPLA F 370 was crossing PK 309.

d. ABQ 406 also reported TCAS warning.

e. Both aircraft were maintaining their levels on radar.

f. Video Display is 12 seconds behind and displays every 6 seconds the position.

g. Any level change between two pick up of 6 seconds will not be monitored on radar.

h. In an occurrence 2 ½ months ago, due to false transponder indication of a military aircraft a TCAS warning was generated on civil aircraft whereas both aircraft were seen maintaining level at radar.

i. He has not received any training on TCAS.

1.21.5 **Witness No. 5 Captain of PK-370**

a. He heard PK-309 announcing TCAS-RA.

b. He heard all the calls of PK-309.

c. He also heard ABQ 406 call for RA activation.

d. Visibility was good and he was visual with PK-309.

e. He monitored the crossing of PK-309 both visually and on TCAS at-900.

f. PK-309 was on his TCAS for the entire period.

g. He was visual with ABQ-406.

h. He was unable to describe TCAS system correctly.

1.21.6 **Witness No. 6 Senior Technician Avionics Overhaul (Instrument Sho)**

a. He tested the AOA sensor S NO 01177 on local tester as per vendor specification.

b. He is testing this component for the last 7-8 years.

c. The AOA sensor was received on 27/12/04. Initial test were completed on 25/02/05 and component was released on 03/03/05.

d. Three resolvers were found out of calibration and the movement of the AOA Vane was sticky so the bearings were changed.

e. The frequency of bearings found sticky is twice a year. It is caused due to damaged vanes. He has no authorization to test this equipment?

f. He has an approval of 737 class III pressurization system and an independent worker.

1.21.7 **Witness No. 7** Aircraft Engineer, overhaul (instrument shop)

a. He is employed as Aircraft Engineer (Avionics) since 1999.

b. AOA Sensor Serial No 01177 was brought to shop on 28th of December 2004 for reported defect "As per TSR".

c. Its resolvers were found out of calibration.

d. The resolvers were recalibrated and unit was released from shop by him on 8 March 2005.

e. The AOA sensor was taken up for rectification on 23rd Feb 2005. It took thirteen days to repair it because there were no urgent requirements communicated either by QS or by Tech. Services.

f. TSR is abbreviation of "Technical Services' Requirement". If there is some repeated snag on aircraft and Tech. Services desire a specific task to be performed, then, a TSR is raised for a specific job.

g. He is familiar with TSR but it does not come to him. They get the U/S tag depicting "As per TSR" and shop QS people brief us about the TSR.

h. The job performed by the shop personnel is recorded in component work package and history card of the unit and not on a TSR form.

i. Actions carried out were not recorded on TSR for AOA sensor # 01177 which removed from AP-BGR.

j. The job done was recorded in the maintenance work package and history card.

k. It is not at all an appropriate practice to write "AS PER TSR "on the work sheet.

l. Details of the snag must be written on unserviceable tag.

1.21.8 **Witness NO 8 Sami Hashmi, Aircraft Engineer of Technical services.**

a. He raised the TSR on the request of Manager Engineering (QS) Mr. Shakeel of Instrument and Overhaul SHOP.

b. Mr. Shakeel informed him that there were a number ADCs removed from AP BGR & tested and found serviceable.

c. He further informed him that these ADCs have indicated some problem with AOA Sensor NO 1 through registering bite code 00001 that is why he raised a TSR for removal of AOA Sensor NO 1.

1.21.9 **Witness NO 9 Manger Engineering Quality Control (Avionics Shop).**

a. He advised Technical services to remove AOA # 1 from BGR as it had registered Bite 0001 recorded.

b As per his experience, ADCs were wrongly removed, while its memory record shows that it is not ADC but AOAS Sensor which is u/s therefore I informed and advised for AOAS removal.

c. When he was asked to suggest any improvement of the system, he could not suggest any improvement.

2. ANALYSIS

2.1 The evidence collected from Karachi radar, air traffic control, DFDRs, maintenance records, witness interviews and TCAS training facilities has been analysed in the light of expert opinion given by Airbus Industries, Toulouse, France. It has been observed that the evidence of radar video, ATC audio (R/T) and Digital Flight Data Recorder of PIA-310 aircraft support each other as far as the triggering of RA is concerned. However the altitude changes as recorded by different equipment do not collaborate by changes in other parameters such as pitch angle or engine power. Following is the step by step analysis of various areas of investigations.

Technical Analysis

2.2 The analysis of the event in the light of DFDR data and history of defects revealed that there was some problem with the altitudes reported by the DFDR and observed by the area control radar after the event. The DFDR data also indicated that there was an off set of AOA sensor # and the behaviour of the AOA sensor was erratic. The most important area of investigation appeared to be the fact that altitude increases as recorded on DFDR were not in conformity or supported by other data such as pitch, trim and engine power etc. Triggering of RA without TA was another area of technical analysis. Hence services of Airbus Industries were needed for simulation of the event and determine the relationship between AOA sensor malfunction and its effects on TCAS RA and altitudes recording on DFDR.

2.3 Both the aircraft were checked for RVSM certification and serviceability of their minimum equipment. The analysis did not reveal any anomaly.

2.4 **Utilisation of Services of Airbus Industries Toulouse, France** The Head of International Flight Safety, Mr Thierry Throeau. airbus Industries Toulouse came to know the occurrence through international media and immediately

offered their specialist support. SIB accepted the offer and requested Airbus facilities to:

2.4.1 Down load the DFDR of the A-320 aircraft of Air Blue for which no facility was available in the country.

2.4.2 Utilise Airbus industry's OSCAR facility for simulating TCAS scenarios between A-310 and A-320 with the help of DFDR data and determine whether an RA can be triggered without a TA.

2.4.3 Provide specialist support for analysis of TCAS equipment, TCAS logics, DFDR parameters and flight sensors.

2.4.4 Whether the A-310 went into porpoise due to weight / Balance problem or getting into transonic speed on descent.

2.5 **Requiring Simulation of TCAS scenarios** Aim of the simulations was to answer the following basic questions:

2.5.1 Was the triggering of TCAS due to busting of level by any of the aircraft or it was due to some equipment malfunction

2.5.2 Is it possible to have a RA without a TA during real situation contrary to the theory given for TCAS equipment and simulator training provided to aircrew where every RA is preceded by a TA?

2.5.3 Were the post TCAS-RA actions of by aircrew correct and in accordance with training?

2.6 **Simulation and analysis of TCAS event by Airbus Industries**

2.6.1 **Creating a Video Clip of the occurrence** A video picture of the occurrence was produced by entering flight parameters from digital flight recorder data in the TCAS simulator software. The difference of altitude level was taken as a reference altitude for satisfying altitude and range tests. It was observed that a/c were never in a range where potential threat of collision existed. However the simulator showed the nose up and down behaviour of PIA aircraft after the encounter.

2.6.2 **Analysis by Airbus Specialists** The initial analysis by Airbus Industries concluded that it was some turbulence which caused aircraft to climb and gave RA. It also explained that though a TA is always preceded by RA but in rare cases such as turbulence it is possible to have an RA without a TA. These conclusions were not convincing as per existing weather conditions. Hence, after a number of debates on the findings between SIB and airbus industries it was concluded that the turbulence was not the cause of TCAS advisories. Hence a deeper analysis of the DFDR data was carried and final analysis by Airbus Industries is as follows:

2.6.3 **A-310 behavior.** An offset between the AOA1 and AOA2 of $+2.5^0$ approximately is noticed. At 15.06.43 the AOA1 is recorded above 10^0 (clean configuration) and the stall warning is activated as per design (cf. figure 4.1). This AOA anomaly is not considered as a recording anomaly as it is seen by FWC and DFDAMU; the AOA1 value did not work properly. At time 15.06.24 – The aircraft speed and altitude start slightly to increase. Around 15.06.29, TAOA1 increases to $+6.5^0$ and the barometric altitude (ALT) increases to a maximum of 36260ft.

2.6.3.1 To note that the recorded elevators, pitch and VRTG value are constant, which indicates that **"The aircraft remains physically on its flight level and confirms the fact that the AOA1 data did not work properly."**

2.6.3.2 Before and after the event we notice some repetitive AOA1 jumps (cf. figures 4.5 and 4.6) which are considered as spurious.

2.6.3.3 The recorded barometric altitude ALT comes from ADC1. ALT is corrected from AOA1 and each "spurious" offset explains the virtual recorded ALT increases, while the aircraft remains at the same flight level.

2.6.3.4 At time 15.06.32 – Evasive action (cf. figures 4.1 and 4.2). AP2 is disengaged and nose down order is applied (elevator to $+1.5^0$). The throttles are retarded from 62^0 to 45^0, which leads to ATHR disengagement and EPR decreasing value from 1.22 to 0.8.

2.6.3.5 The elevators movement ($+1.5^0$) is linked to a force of approximately 5daN applied on the Control Column. 5daN

is below AP disconnection threshold (15daN). Consequently, the AP disconnection was most probably commanded by the pilot.

2.6.3.6 The altitude reported by ADC 1 was not consistent with the one reported by ADC 2 (discrepancy around 300 ft).

2.6.3.7 This difference in altitude was already evidenced during the previous flight of that a/c, same day in the morning. This difference in altitude is likely due to a faulty input to ADC 1 or problems within ADC outputs. Autopilot was connected to ADC 2, and did not notice the small discrepancy between ADC1 and 2.

2.6.3.8 TCAS is connected to two transponders (XPDR), only one selected at the same time. Each transponder receives one ADC source at the same time. No altitude correlation is done by the transponder.

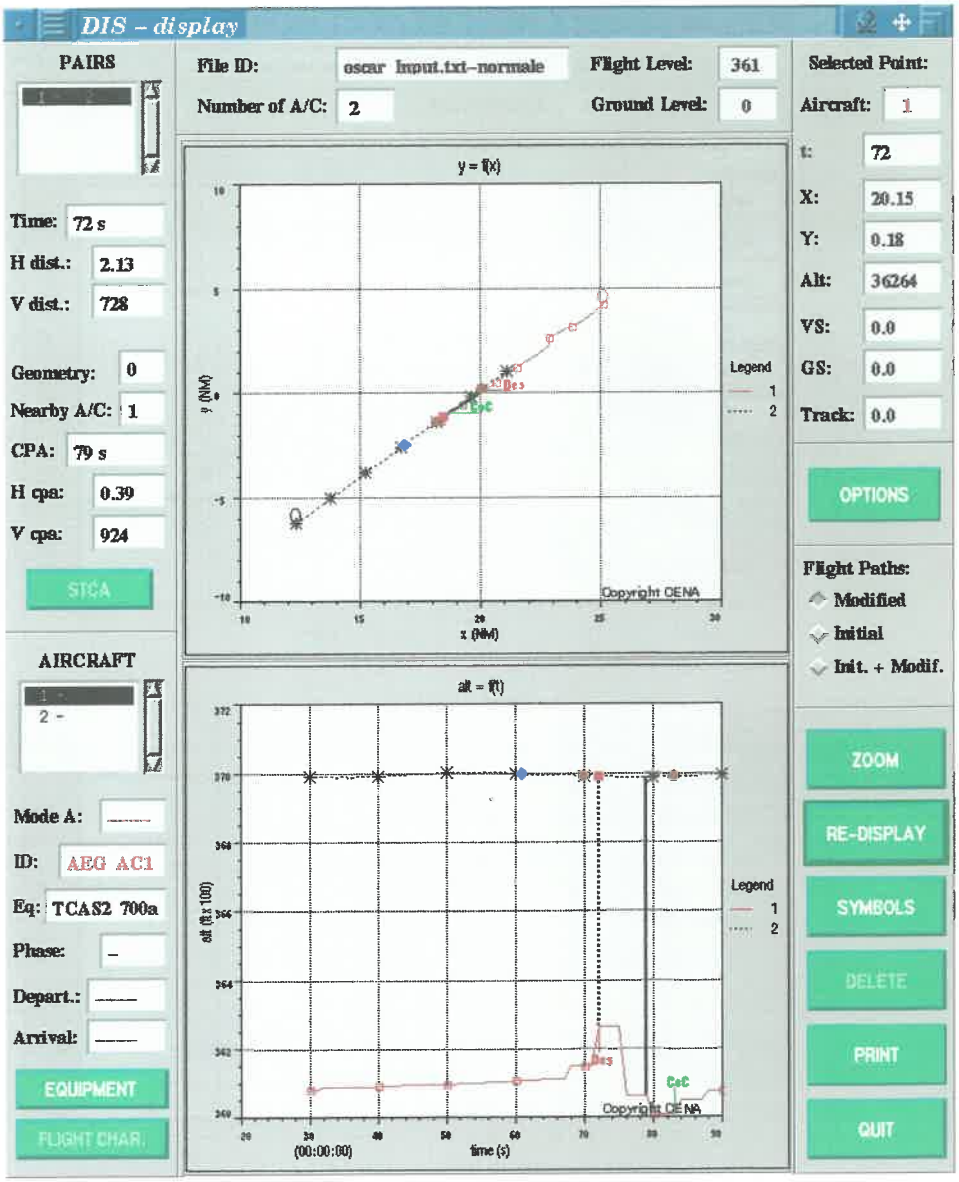
2.6.3.9 TCAS v7.0 logic uses the barometric altitude supplied by the transponder selected on the control panel. The calculation of V/S is done by derivation of the barometric altitude.

2.6.3.10 Sudden altitude change by A-310 due to faulty AOA sensor #1 amounts to high vertical speed of an intruder for A-320. The TCAS calculates it as a high closure rate between two aircraft.

2.6.3.11 TCAS RA triggered in both conflicting a/c (coordinated RA).

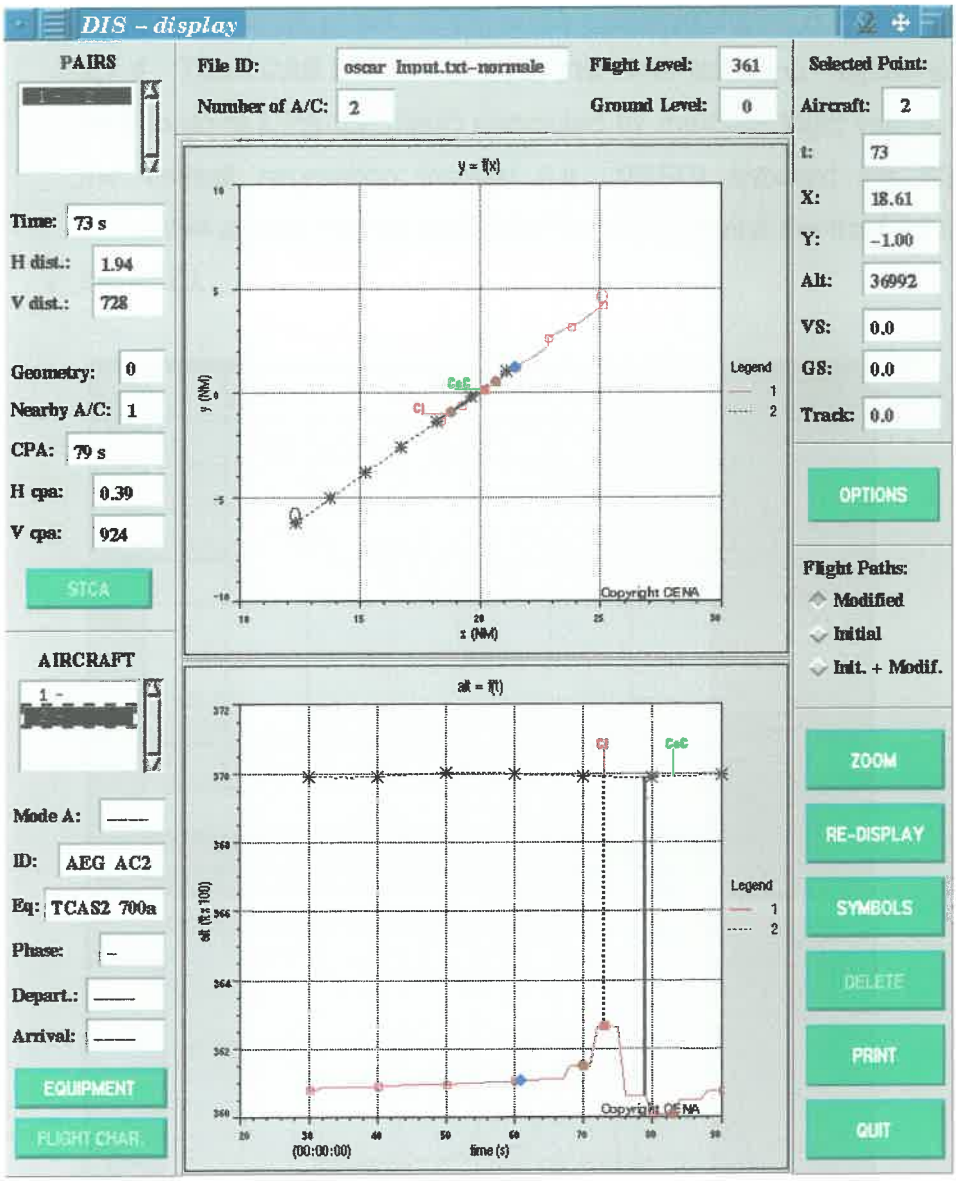
2.7 TCAS Simulation by Centre of Airbus Computer Simulation CENA)

2.7.1 Airbus Industries contacted CENA, for analysis of the event with the help of OSCAR facility, which is set of integrated tools to prepare, execute and analyse scenarios of countries involving TCAS II aircraft. The OSCAR facility simulated the Pakistani event where both aircraft were equipped with TCAS II logic version 7. The simulated encounters shown here,



2.7.2

Encounter simulated with TCAS II version 7.0
onboard the A320 and the A310
RAs onboard aircraft the A310 (Shown in full red line)



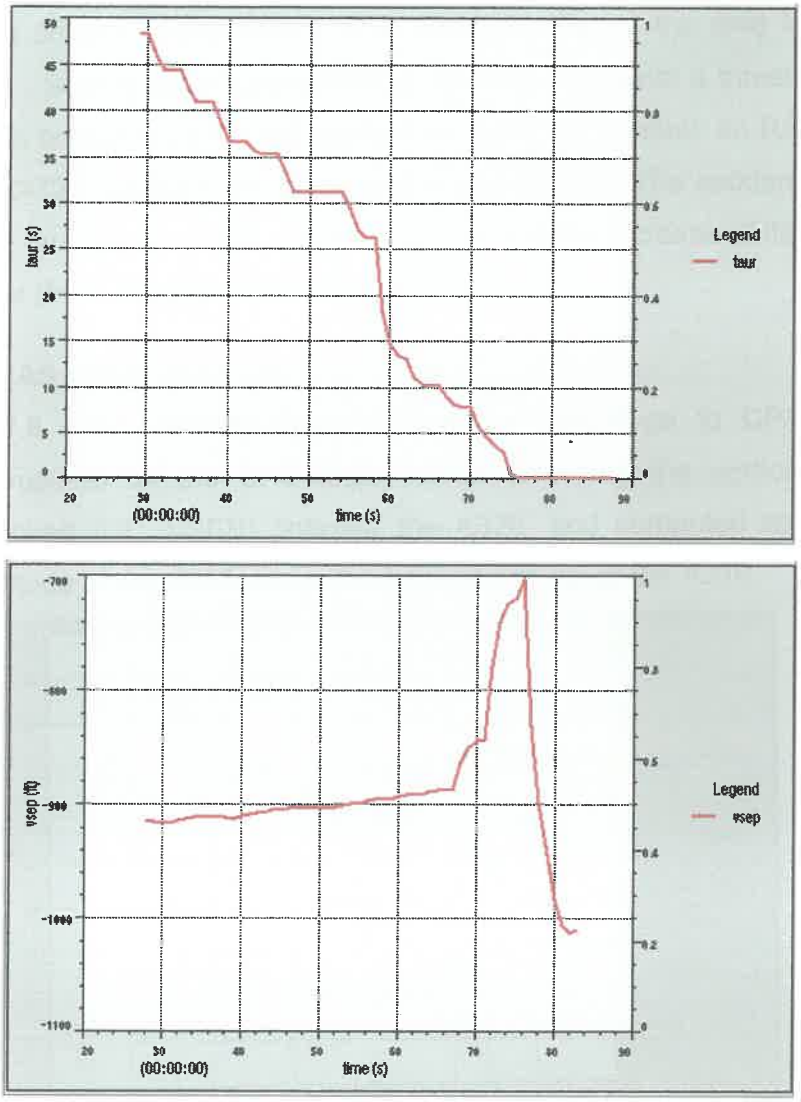
Encounter simulated with TCAS II version 7.0
onboard the A320 and the A310
RAs onboard aircraft the A320 (Shown in black dotted line)

2.7.3 The A310 receives a TA, and 2 s later a "Descend" RA, which lasts 11 s.

The A320 receives a TA, followed 3 s later by a "Climb" RA, which lasts 10 s.

The result of this simulation is in conformity to the TCAS data for the RA, for the A320. The simulations were performed with both aircraft reporting their altitudes in 25 ft or 100 ft, and with either 1 ft or 100 ft increments for own altitude, resulting in the same TA and RA sequences.

2.7.4 **The TCAS behaviour of A-310** The following figure shows the time-to-go to CPA (i.e., taur) computed by the CAS logic versus time and the vertical separation tracked (i.e., VSEP) onboard the A320, and computed as the tracked altitude of the A310 minus the tracked altitude of the A320.



Time to CPA (taur) and Vertical separation tracked on board the A310 (VSEP)

t=28 s: taur<48 s ⇒ range test passed for TA from this time on

t=70 s: VSEP<850 ft ⇒ altitude test for TA passed ⇒ **TA**

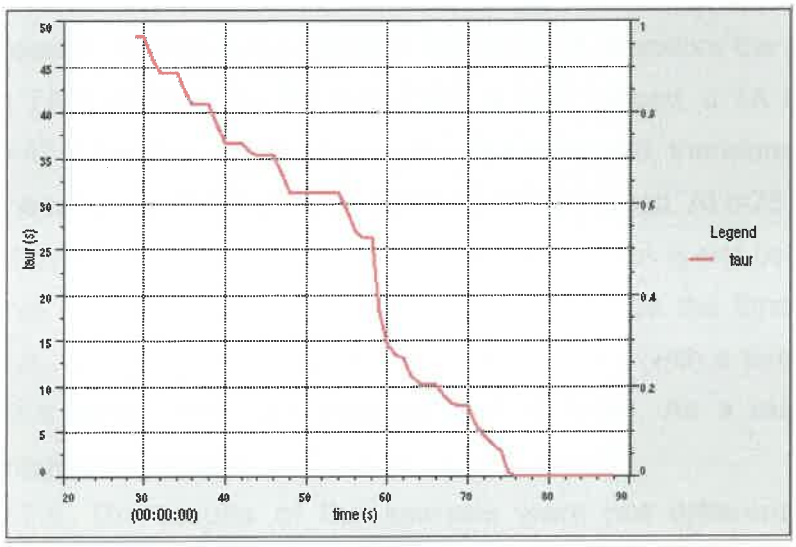
t=47 s: taur<35 s ⇒ range test for RA passed from this time on

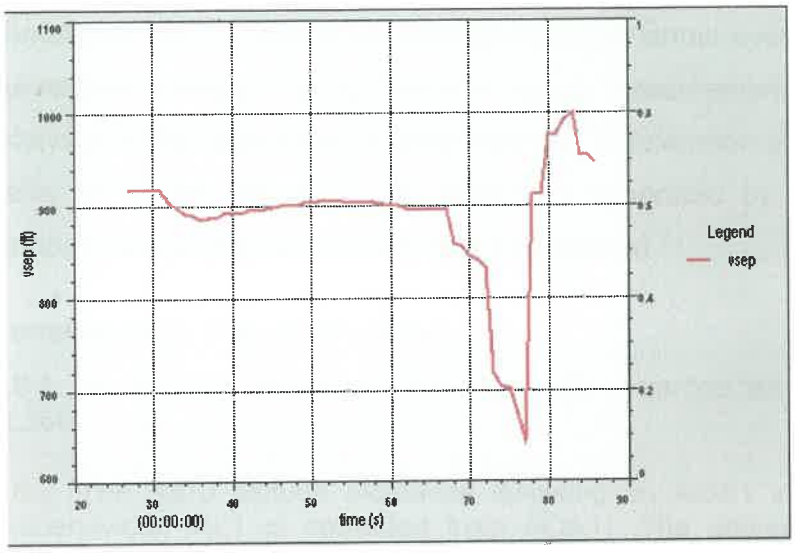
t=72 s: tauv<35 s ⇒ altitude test for RA passed ⇒ **RA**

2.7.5 This figure shows that the taur is below the 48 s threshold at t=28 s, therefore the range test for the triggering of a TA is passed from this time. At t=70 s, the VSEP is below 850 ft, therefore the altitude test for a TA is passed. As the range test is also passed, a TA is triggered. At t=47 s, the taur passes below the 35 s threshold, therefore from this time, the range test for the triggering of an RA is passed. At t=72 s, the VSEP is above 700 ft therefore the altitude test for an RA is not passed thanks to this criteria. Nevertheless, it is passed because the time to co-altitude (i.e., tauv) suddenly passes from 137 s to 24 s (with a threshold equal to 35 s because own is not tracked as level). As a result, an RA is triggered at t=72 s because the range test is also passed. The sudden decrease of the tauv parameter is explained by the sudden increase of its own vertical rate (from 360 fpm to 1900 fpm).

TCAS behaviour A320

2.7.6 The following figure shows the time-to-go to CPA (i.e., taur) computed by the CAS logic versus time and the vertical separation tracked (i.e., VSEP) onboard the A320, and computed as the tracked altitude of the A320 minus the tracked altitude of the A310.





Time-to-go to CPA (taur) and Vertical separation tracked on board the A320 (VSEP)

t=31 s: taur<48 s ⇒ range test passed for TA from this time on

t=70 s: VSEP<850 ft ⇒ altitude test for TA passed ⇒ **TA**

t=47 s: taur<35 s ⇒ range test for RA passed from this time on

t=73 s: tauv<25 s ⇒ altitude test for RA passed ⇒ **RA**

2.7.7 This figure shows that the taur is below the 48 s threshold at t=31 s, therefore from this time the range test for the triggering of a TA is passed. At t=70 s, the VSEP is below 850 ft, therefore the altitude test for a TA is passed. As the range test is also passed, a TA is triggered. At t=47 s, the taur passes below the 35 s threshold, therefore from this time the range test for the triggering of an RA is passed. At t=73 s, the VSEP is above 700 ft therefore the altitude test for an RA is not passed thanks to this criteria. Nevertheless, it is passed because the time to co-altitude (i.e., tauv) suddenly passes from 100 s to 11 s (with a threshold equal to 25 s rather than 35 s because own is level). As a result, an RA is triggered at t=73 s.

2.7.8 **The results of the analysis were not different from Airbus analysis. The CENA report concludes that:**

"This analysis confirms the recorded data for the A320. The A320 received a climb RA, which lasted 10s. It is possible that no preliminary TA was triggered due to the rapid variations on the A310 altitude. Events in which RAs are triggered without any preliminary TA are rare events, but

sometimes occur. They often correspond to abnormal events in terms of surveillance (Mode C jumps, error in range measurement). In the case analysed in this report, the important vertical acceleration of the A310 can have led to this situation. The advisories generated by the A320 are compatible with the surveillance data it processed."

2.8 **Conclusion by Airbus Industries**

2.8.1 An A320 is flying at flight level 370 towar5ds an A310 on the FL360.

2.8.2 The A310 altitude increases following an AOA1 incorrect offset misbehaviour (ALT is corrected from AOA1). The attitude parameters (elevators, pitch, vertical load factor) indicate that there is no aircraft climb movement.

2.8.3 There was malfunction of AOA 1 sensor, It was providing erroneous data at random basis, whereas it was working fine for the majority of the time.

2.8.4 The A310 TCAS sends to the A320 the false information that it is climbing.

2.8.5 Consequently, the A320 TCAS computes a RA (resolution advisory – real collision threat) with an "up advisory" order. The A320 have a visual contact with the A310 and does not apply the climb advisory of the TCAS.

2.8.6 As the TCAS message of the A310 is not recorded on the DFDR, the assumption is that it may have computed a Resolution Advisory with a "descend" advisory, in this specific case without prior TA message (as per design). The crew reacted, most probably by the deactivation of the AP, and successive nose down and up order applications. Following the crew order, the VRTG reached the extreme of [-0.23g; + 1.74g].

2.8.7 The assumption is that the reaction to the TCAS vertical speed target (-1500 ft/min) is likely due to the fact that no traffic advisory has been computed before.

2.8.8 The evasive actions of PIA aircrew were incorrect.

2.8.9 A-320 aircrew did not take evasive action which is contrary to standard procedures.

2.8.10 The RA is normally preceded by TA but in rare cases such as Pakistani event it is possible to have an RA without a TA.

2.9 **Conclusion of Technical Analysis.** Scrutiny of technical records in the light of analysis presented by Airbus Industries revealed that defect report

No 240, noted by the shop on the overhaul and repair report **(See Appendix G 4) is of prime importance to determine cause of occurrence.** The Air Data Computer S NO 9510 1966, which was removed on 30 11-04 due to pilot's defect report. It was tested and declared serviceable and no efforts were made to determine the cause of it's failure. Even when the shop check indicated a faulty AOA sensor responsible for ADC failure; the same was not taken seriously for any corrective action by PIA engineering. The shop checks clearly indicated that whereas the ADC was serviceable but Angle of Attack Sensor was unserviceable.

2.10 In fact there was an immediate need to replace the AOA Sensor #1 but it was not removed. However after the occurrence it was removed against the same defect i.e. "**ADC light came ON" reported by aircrew on 30th November, 2004.** Now it was removed through a special document known as "Technical Service Requirement (TSR), **Appendix 5** initiated by Technical Services.

2.11 **How and why a Technical Service Requirement was raised to remove defective angle of attack sensor?** The TSR for removal of AOA sensor was raised by an engineer of technical service on 13th December, 2004. As per the requirements stated in QC Advisory for raising a TSR, **Appendix G-8(i)**; there was no reason for technical services to raise it. As per the statement of concerned engineer, he raised it because engineer (quality services) of instrument overhaul shop asked him to raise the TSR so that AOA sensor could be removed from AP BGR. It was further explained that a number of Air Data Computers had been removed from aircraft, checked and found serviceable during shop checks. However these had registered faults for AOA sensors. A further analysis of the angle of attack sensor defects in the past revealed that engineering personnel were well aware of the problem. There have been number of AOA sensors removals from aircraft and these were found out of

calibration. The exact cause for AOA sensors going out of calibration was not established. The problem is common with other operators. In the year 2001, there was a regional conference on the subject and was attended by PIA personnel, where causes of AOA sensors unserviceability were discussed. Appendix G 8 (ii) gives point of view of different operators. The common reasons given by Sharp/Qantas are physical damage to AOA sensors by technicians during maintenance using high platforms or washing by high power water jets. However Jhonson /American did not correlate it to any kind of physical damage to AOA sensor. How AOA sensor under discussion went out of calibration could not be established. Whatever may have been the reason for AOS #1 going unserviceable, the mere fact is that the ADC registered it's unserviceability on 30th November 2004 when pilot reported ADC failure light. The shop check of ADC revealed that ADC itself was serviceable but AOA sensor was faulty. On 13th December a decision to remove it was taken at manger engineering levels through a TSR. However as the defect monitoring was not coordinated the way it should have been; hence it was not removed from aircraft till the occurrence. It was finally removed after the occurrence on 27th December, 2004. Had it been removed in time the occurrence could have been avoided.

OPERATIONS ANALYSIS

2.12 The investigation was focussed to find answers to following two questions:

a. Why did the TCAS-RA was generated with or without Traffic Alert?

b. Circumstances leading to a vigorous manoeuvre in response to Resolution Advisory and injuries to passengers/crew?

2.13 **Cause of Resolution Advisory (RA).** The RA is normally preceded by a TA, however, in RVSM airspace and TCAS II version 7.0 the possibility of

RA coming without a TA exists during cruise. The aircraft are flying on reciprocal headings on same track with 1000 ft separation. When separation is reduced to less than 850 ft for TA and 700 ft for RA the alert and advisory command is generated. Therefore, if two aircraft are separated by marginally more than 850 ft and suddenly one of the aircraft climbs with a rate that projects less than 35 seconds to CPA; the RA would be generated without TA as altitude test is satisfied. The two aircraft also satisfy the range test. The 21 feet per minute rate of climb for two seconds when range was less than 6 nm and vertical separation about 700 feet projected a CPA in about 10 seconds and collision in 38 seconds, if Air Blue flight was exactly at assigned altitude. Moreover, if time is taken after 02 sec of 21feet rate of climb then CPA is reached in 08 seconds and collision in 36 seconds. However, Air Blue is found maintaining accurate altitude on radar and CENA simulation that TA also came for about 2 seconds, which is on A-320 DFDR as well, when PIA came at less than 850 ft separation. The Airbus data, though, shows a climb of 262 ft by PIA as against 242 ft on DFDR extracts provided by PIA. Therefore, it is concluded that TCAS-RA was generated for only two seconds followed by RA.

2.14 The reason for RA remaining for 10 seconds and followed by TA for 08 second even after PIA responding by descent is possible on two accounts only as follows:

a. Any one aircraft responding contrary to RA.

b. Any one aircraft descending and then climbing after RA, while remaining within an altitude and attitude, which represents an RA and TA envelope.

2.15 The Air Blue radar trace and DFDR show no altitude or altitude change in flight. The PIA flight response to RA is completely available on radar trace and DFDR. It shows that in response to RA aircraft entered into a descent by 100 ft only and then went into porpoise. Subsequently, PK-309 remained within 150 ft of RA altitude during porpoise for 22 seconds until it settled down at 850 ft vertical separation.

Therefore, it is concluded that RA was followed by TA and RA descent command increased, as claimed by P IA 309 pilots, due to getting into porpoise and projecting TA and RA situation within Air Blue flight.

2.16 The cause of climb by PK-309 has been discussed in technical analysis in detail. It is evident from PK-309 DFDR that aircraft actually did not climb as climb is not accompanied by any change in Vertical Gs, Pitch Angle, Elevator Deflection, Control Column position or Engine settings. Moreover, the auto pilot is engaged. The DFDR indicates a climb and increase in speed. The inputs to DFDR and TCAS computer are received from same source i.e. selected Air Data Computer. The technical report shows that in addition to altitude and speed inputs, the angle of attack indications were also erroneous. It is therefore concluded that TCAS-RA was not generated because of cockpit crew's aircraft handling. Furthermore, same changes could not be observed in the cockpit before the incident.

Aircrew Response to TCAS RA

2.17 The TCAS display screen in A-310 shows only 06 NM RA range distance on the dial unlike other aircraft in PIA. Any TA or a possible intruder beyond is indicated by an arrow pointer on the periphery of the display showing direction and altitude. Though, TA is accompanied by an synthetic aural warning. While in other aircraft the reciprocal traffic is displayed, if within ± 2700ft when about 40 nm. In this incident TA came for about two seconds followed by RA. The word traffic is announced twice, therefore, TA may not have been sounded completely and RA command came. During a night cruise and then minimum radio communication due to less traffic, the pilot flying with Auto Pilot selected may not be ready for TCAS-RA response. It is for this reason a 05 sec assessment reaction time is in built in TCAS to safely and smoothly avoid 600 ft CPA with intruder. The computer based training of TCAS at PIA

training centre, doesn't cover the related scenarios and does not give a hands-on experience. Furthermore, the aircraft handling characteristics in RVSM airspace also change and pilots are rarely exposed to manual handling of aircraft control at 37000 ft and around. Therefore, the inadequate understanding of TCAS and unfamiliarity within RA response resulted in immediate disengagement of AP, retardation of throttles to idle and pushing nose down. The nose was pitched steeply and thus correction was applied. The unfamiliarity with sluggish response of controls caused over corrections leading to aircraft getting into porpoise. The porpoise was controlled in about 20 seconds during which minor injuries to passengers/cabin crew occurred. It is therefore concluded that TCAS-RA response was not according to the procedures due to the inadequate knowledge and unfamiliarity with aircraft manual handling at high altitude. Inputs from Airbus and DFDR indicates that over controlling was not due to air craft going into transonic range in RA descent. Evidence collected from Karachi radar, air traffic control, DFDRs, maintenance records, witness interviews and TCAS training facilities has been analysed in the light of expert opinion given by Airbus Industries, Toulouse, France. It has been observed that the evidence of radar video, ATC audio (R/T) and Digital Flight Data Recorder of PIA-310 aircraft support each other as far as the triggering of RA is concerned. However the altitude changes as recorded by different equipment do not collaborate by changes in other parameters such as pitch angle or engine power. Following is the step by step analysis of various parameters.

2.18 **Analysis of Altitudes Flown by PK 309 and Air Blue-204:**

2.18.1 As per radar picture PK-309 was maintaining FL 361, while ABQ 406 is maintaining FL 370 which means a difference of 900 feet was generally maintained between respective altitudes.

2.18.2 A-310 is maintaining flight level 36150 feet till 15:06:02. It shows a gradual climb of 30 feet in next 24 seconds i.e. it's altitude is 36183 at 15:06:2.

2.18.3 In next three second A-310 has shown a rate of climb 0f 21 feet per second, 21 feet per second and 15 feet per second respectively. It may be noted that at 15:06:28 and 15:06:29, the time remaining for possible collision based on relative altitude of 758 feet between two aircraft would be 36 seconds. It is very close to 35 seconds for triggering of RA and it would be perfect if we assume that Air Blue is approximately 10 to 20 feet lower than its assigned level of 37,000 feet thereby reducing the relative altitude to 750 feet. Hence the altitude test is satisfied under these conditions for TCAS II installed at A 320 of Air Blue.

2.18.4 At the same time the pitch of the A310 shows a sudden change from +ve 1.4 to –ve 1.4 which is an indication of sudden dive by the aircrew. For next 30 seconds the pitch is changing abruptly and aircraft went into a porpoise.

2.18.5 The DFDR also shows accompanied changes of engine RPMs and Gs.

Function of Auto-Pilot

2.18.6 The PF had selected auto pilot-2, which was serviceable. Any change in altitude erroneously or due to atmospheric pressure changes are to be registered by ADC and change in altitude is to be corrected by Auto Pilot so as to maintain a pre-selected altitude. In this incident Auto Pilot-2 was selected, however, when ADC altitude increased without aircraft actually climbing the Auto Pilot did not take the aircraft down. In fact, on erroneous increase in altitude by 262 ft above selected altitude should have physically taken the aircraft 262 ft below selected altitude by Auto Pilot. This anomaly can occur with serviceable Auto Pilot when ATC transponder selected is different from corresponding Auto Pilot altitude inputs. In this

scenario Auto Pilot-2 was getting inputs from ATC Transpondder-2, however, ATC Transponder-1 was selected for transmission to ground radars and TCAS Computer. Therefore, altitude change selected on ADC/ATC Transponder-1 due to faulty AOA Sensor was not corrected by Auto Pilot-2.

2.19 **Valuating TCAS training**. The board could not access the syllabus either from operations or from Flight standards. The co opted representative informed the investigating team that complete training to A 310 crew is imparted in PIA training centre. It was learnt that PIA training centre has no simulator for Airbus 310. Hence the computer based training was analysed. Again it was learnt that CBT consisted of a number of TCAS scenarios; which do not provide any hands on training to the aircrew. The CBT was not a replacement of simulator training; it did not provide any HANDS ON training to aircrew in any expected situations.

2.20 **Simulator Training Facility Dubai**. The simulator training session arranged by PIA while the simulator was used for a set of PIA crew. The primary aim was to observe the scenarios simulated by simulator and the training for aircrew response. A questionnaire was prepared to record the observations in the presence of experienced pilots. **(See Appendix "J ")** for details. Following observations were made:

a. A Traffic Advisory (TA) always preceded a Resolution Advisory (RA).

b. The time available to initiate evasive action was always more than 5 seconds.

c. The RA climb / descend rates did not change even if the evasive action was delayed for 5 seconds.

d. TA remains for 45 seconds before changing into an RA on range test.

e. Once an RA has been received, there was no need to apply sudden positive or negative Gs; rather a smooth action was enough.

f. The training scenarios were barely adequate to prepare aircrew to handle different situations.

2.21 **Evaluation of aircrew's understanding of TCAS System**

A number of pilots including those not involved in the occurrence were interviewed. Their understanding of the TCAS system, in general, and that of evasive actions on RA in particular was found incomplete and contrary to reference manuals. They could not provide satisfactory answers to questions regarding:

a. **Principles of operations** including envelope in which PA, TA and RA would appear (Ref 1.10. 56 Rev 34 A 310 TCAS General Reference Manual).

b. The time for **initiating response** once an **RA** has been received. The aircrew of PK 309 insisted that once on RA has been received, the evasive action has to be taken instantly and without any regards to Gs. Whereas as per collision avoidance System, User's Manual Rev 5-02/2000 Page 24-25;

"The crew response is required to the initial RA within 5 seconds and G-forces of ± 0.25G. This force is similar to that experienced when initiating a climb or descent".

c. It further says "When the initial RA is changed the crew must respond within 2 ½ seconds."

i. The above references are important to understand the difference between **what should have been aircrew's reaction to RA** for "Descend Descend"? And **what was their reaction?**

ii. The PF applied controls for descent without any consideration to Gs and time available to react which was 5 seconds. The aircrew of PK-309, did not act smoothly.

d. The pilot flying while answering a question regarding time available once RA had been received, maintained that within 5 second he had to complete his evasive action and had there been a change in RA, he would have completed his actions within 2 ½ seconds. The

evidence of sudden dive and then over correction leading to porpoise confirms his actions and implies that the aircrew were not monitoring the traffic on TCAS and when suddenly the TA changed into an RA with aural warning; they woke up to the situation and the instant behaviour was to apply sudden diving manoeuvre instead of prompt but smooth manoeuvre without causing appreciable downwards movement of the aircraft.

e. PNF of PIA aircraft during interview maintained his erroneous understanding for TCAS RA response and even stated that they had been trained for such response. He also expects that in such a situation there would be some injuries in passenger cabin. PF stated that his response was steeper and tougher because PF of Air Blue did not take evasive action.

f. PF of Air Blue did not take any evasive action on 10 sec RA because he was visual with PIA aircraft. This is contrary to ICAO, JAR-OPS and Euro control recommendations to always follow TCAS orders regardless of external conditions such as good visibility or visual contact with intruder.

3. FINDINGS

3.1 The Occurrence

3.1.1 On PIA 22nd December 2004 near Rahim Yar Khan (Murli) PIA flight PK 309 and Air Blue flight ABQ 406 were flying on reciprocal tracks with assigned FL 360 and FL 370 respectively under ACC Karachi Sector North.

3.1.2 The aircraft were RVSM certified and were having valid Certificate of Airworthiness.

3.1.3 The weather and visibility were fine.

3.1.4 PK-309 (A-310) observed an a/c coming from opposite direction with 800 feet vertical separation. The altitude difference decreased to 700 feet and a/c received a TA immediately followed by resolution advisory (RA).

3.1.5 Pilot Flying PK 309, received RA for Descend and took evasive action after disengaging the auto pilot.

3.1.6 PIA 310 response was not smooth and it went down with vigorous negative Gs and then pitched up with positive Gs resulting porpoise within 150 feet altitude.

3.1.7 TCAS RA activation was confirmed by aircrew of both aircraft on RT after crossing each other at Murli.

3.1.8 The RA duration determined by computer simulation and DFDR data was approximately for 10 seconds.

3.1.9 The evasive response was incorrect and resulted in porpoise causing injuries and panic in the passenger cabin.

3.1.10 Air Blue 320 flight ABQ 406 received advisory for CLIMB for 10 seconds but the captain did not take any evasive action, which he should

have taken regardless of the fact that there was no threat of actual collision.

3.1.11 The knowledge of TCAS and RA response in PIA cockpit crew and Operations Directorate is inadequate.

3.1.12 TCAS Computer Based Training does not fulfil training requirements.

3.2 **Technical**

3.2.1 There were no technical snags / defects related to altimeters and TCAS equipment of PIA 310 as well as on Air Blue 320.

3.2.2 The triggering of RA was due to an error in AOA sensor 1 which caused an RA without being preceded by normal TA.

3.2.3 The offset of Angel of Attack sensor was recorded by ADC and noted during shop check as BITE 010001.

3.2.4 All three resolvers of defective AOA sensor were found 3 Deg out.

3.2.5 The unserviceable AOA sensor was removed from AP BGR on 27 December 2004 after the occurrence.

3.2.6 AOA sensor should have been replaced earlier.

3.2.7 Faulty AOA#1 caused the coordinated RA advisories for A310 and A320

3.3 **Weaknesses of PIA Maintenance Management**

3.3.1 The defect of AOA sensor noted by shop was not transferred on fleet defect history i.e. computer software PALMIST.

3.3.2 The defect of AOA #1 was not immediately linked to ATC Transponder/TCAS, hence action to remove AOA sensor from A-310 aircraft by maintenance management did not take place.

3.3.1 A technical service requirement (TSR) for removal of AOA sensor from A-310 was raised by an engineer from technical services on verbal advice of another engineer from avionics shop

3.3.2 The engineer in avionics shop noticed that ADCs, removed from aircraft due to aircrew reported defects, are found serviceable but indicating defects with other components.

3.3.3 A Technical Service Requirement (TSR) was raised but in vain.

3.3.4 The defective AOA sensor was removed from the aircraft on 27th December , 2004 after the occurrence of 22 December 2004,

3.4 Media Reporting

3.4.1 The erroneous and irresponsible media reporting through PIA channels has caused unnecessary panic in the general public.

3.5 FINALIZATION

The occurrence is finalized as

Primary

Failure to replace defective AOA Sensor

Human Factor – Avoidable

Secondary

Inadequate TCAS knowledge / training by PIAC – Avoidable

Contributory

Incorrect Response to TCAS RA

Human Factor – Avoidable

4. RECOMMENDATIONS

4.1 Aircrew understanding of the principles of operations of TCAS equipment is to be improved for its full advantage and standardized in recurrent training. (PIA, Airblue)

4.2 The significance and importance of mandatory/smooth manoeuvre in response to TCAS RA be emphasized in recurrent cockpit crew training. (PIA, Airblue)

4.3 Director Engineering PIAC is to determine through departmental inquiry as to why the defective AOA sensor No 1 was not replaced earlier and improve monitoring system to avoid recurrence. (PIA Engineering)

4.4 Public relation officers of PIAC and CAA should not release any report of an occurrence without consultations with SIB.

4.5 The selection of ATC Transponder should be compatible to Auto Pilot in use and same should be included in FCOM (Flight Operations)