**Federal Department of the Environment,
Transport, Energy and Communications** **No. 1767**

Final Report of the Aircraft Accident Investigation Bureau

on the accident

to the Piper PA31-350 Navajo Chieftain Panther II aircraft, HB-LTC

on 26 May 2000

Zurich Airport, municipality of Rümlang ZH

Bundeshaus Nord, CH-3003 Bern

Ursachen

Der Unfall ist auf eine Kollision mit Hindernissen nach einem Versagen beider Triebwerke zurückzuführen. Die beiden Kolbenmotoren fielen aus, weil das Flugzeug irrtümlich mit Flugpetrol JET A-1 statt mit Flugbenzin AVGAS 100LL betankt wurde.

Die Untersuchung hat folgende kausale Faktoren für den Unfall ermittelt:

- Bei der Bestellung des Treibstoffes trat ein Missverständnis auf.
- Der betreffende Tankwart erkannte die am Flugzeug angebrachten Qualitätskennschilder nicht.
- Der betreffende Tankwart bemerkte nicht, dass das Flugzeug mit Kolbenmotoren ausgerüstet war.
- Der Pilot erkannte die Qualitätskennschilder des Tankfahrzeuges nicht.
- Der Pilot bemerkte die Fehlbetankung auf der Quittung für den Treibstoffbezug nicht.

Folgende Faktoren haben die Entstehung des Unfalls ermöglicht bzw. begünstigt:

- Das Ausflussrohr der Zapfpistole wies einen Aussendurchmesser auf, der eine Betankung des Unfallflugzeuges zuliess.
- Der Ausbildungs- bzw. der Kenntnisstand des betreffenden Betankungspersonals war ungenügend.
- Das Bundesamt für Zivilluftfahrt hat den Betankungsbetrieb vor dem Unfall nie inspiziert.
- Bis zum Unfallzeitpunkt hatte das Bundesamt für Zivilluftfahrt keine Vorschriften bezüglich Ausbildung von Betankungspersonal, Dimension von Ausflussrohren bzw. Tanköffnungen von Luftfahrzeugen sowie über die Kennzeichnung von Zapfpistolen und Tanköffnungen erlassen.

Die folgenden Punkte haben den Ausgang des Unfalls möglicherweise verschärft:

- Der Pilot entschied sich zu einer Umkehrkurve, die ihn auf Kollisionskurs mit Hindernissen brachte.
- Der Rückhaltemechanismus des Schultergurtes funktionierte nicht.

Aircraft Accident Investigation Bureau

Final Report No. 1767

Owner:	Debis Leasing AG, Wagistrasse 21, 8952 Schlieren ZH
Operator:	Lemanair Executive SA, route de l'Aéroport 5, 1215 Genève Aéroport
Aircraft type:	Piper PA31-350 Navajo Chieftain modified to Panther II
Nationality:	Switzerland
Registration:	HB-LTC
Place of the accident:	Zurich Airport, municipality of Rümlang ZH
Date and time:	26 May 2000, 20:23 hrs[1]

Synopsis

Brief description

Aircraft PA31-350 Navajo Chieftain Panther II, HB-LTC arrived in Zurich on Friday 26 May 2000 at 19:10 hrs from Béziers (F) with seven passengers on board. The aircraft was then incorrectly refuelled with 100 l of JET A-1 kerosene instead of aviation gasoline (AVGAS). The pilot took off at 20:21 hrs alone on board from runway 28 of Zurich airport in order to fly back to Geneva. Shortly after take-off, both engines failed and the aircraft crashed while attempting to turn around. The pilot sustained fatal injuries and the aircraft was destroyed.

Investigation

The accident took place on 26 May 2000 at 20:23 hrs. The Swiss air rescue service (REGA) alerted the Aircraft Accident Investigation Bureau (AAIB) at 20:30 hrs. The investigation was opened on 26 May 2000 at approx. 22:00 hrs at the site of the accident in cooperation with the rescue services and the Zurich cantonal police.

[1] All indicated times, unless otherwise specified, are local times and correspond to central European summer time (UTC + 2 h)

The investigation established the following causal factors for the accident:

- A misunderstanding occurred when the fuel was ordered.
- The refuelling attendant concerned did not notice the fuel grade rating placards attached to the aircraft.
- The refuelling attendant concerned did not realise that the aircraft was equipped with reciprocating engines.
- The pilot did not notice the fuel grade rating placards on the tanker vehicle.
- The pilot did not realise the incorrect refuelling on the receipt for the fuel provision.

The following factors allowed or favoured the occurrence of the accident:

- The delivery nozzle on the filler gun was of an outside diameter which allowed the aircraft involved in the accident to be refuelled.
- The level of training and knowledge of the refuelling personnel concernded was inadequate.
- The Federal Office for Civil Aviation never inspected the refuelling operation before the accident.
- Until the time of the accident, the Federal Office for Civil Aviation had issued no regulations on the training of refuelling personnel, the size of delivery nozzles and tank openings on aircraft or on the identification of filler guns and tank openings.

The following points may have exacerbated the outcome of the accident:

- The pilot decided on an about turn which brought him onto a collision course with obstacles.
- The retention mechanism of the safety belt was not working.

Three safety recommendations were made during the course of this investigation.

1 Factual information

1.1 Prior history and history of the flight

1.1.1 Prior history

On 25 and 26 May 2000 aircraft HB-LTC was used for a commercial flight from Zurich to Béziers (F) and back. To this end, the pilot made a positioning flight from Geneva to Zurich on 24 May 2000. The reconstruction of the following events is based on recorded radio conversations and witness statements.

On 25 May 2000 at approx. 07:20 hrs, the pilot placed a telephone order with the refuelling service of Jet Aviation Zurich AG. According to statements from aircraft refuelling attendant A concerned, the pilot asked for the aircraft to be fully refuelled with aviation gasoline (AVGAS) for a flight to France. When aircraft refuelling attendant A arrived at the aircraft, the pilot was present. The refuelling attendant saw the winglets[2] on the HB-LTC and asked the pilot whether the machine had been modified and therefore needed jet kerosene. Before the pilot could even answer, the refuelling attendant realised, from the square engine housings, that the machine was equipped with reciprocating engines. The pilot confirmed that HB-LTC had been modified but pointed out that this modification involved only the airframe and that the aircraft had not been converted to turboprop operation.

Refuelling attendant A then filled the HB-LTC's four fuel tanks with 372 l of AVGAS 100LL (low lead). The aircraft was therefore fully refuelled and at that time had 726 l of fuel.

Refuelling attendant A later reported that he had not noticed markings which described the types of fuel permitted for this aircraft, either on the wing or on the tank seals.

During the refuelling operation, which ended at approx. 07:30 hrs, the pilot was in the cockpit. Nobody observed him draining the tanks after refuelling.

The seven passengers for the flight to Béziers (F) arrived on 25 May 2000 at about eight o'clock in the morning at the General Aviation Centre (GAC) at Zurich airport. At 08:18:42 hrs the pilot received start-up clearance from Zurich Apron (ZRH APR) and at 08:26:25 hrs indicated that he was ready to taxi. Taxi clearance was granted without delay and the aircraft taxied to the holding point of runway 28. Several passengers later stated that the pilot carried out a run up of the engines while the following time of waiting. At 08:32:01 hrs HB-LTC indicated to aerodrome control (Zurich Tower – ZRH TWR) that it was ready to take off. The aircraft was queued in the traffic and was cleared for take-off at 08:45:27 hrs. The aircraft landed in Béziers (F) some two hours later.

On 26 May 2000 between 15:35 and 15:45 hrs HB-LTC was refuelled in Béziers with 107 l of AVGAS 100LL. The aircraft then flew with the same passengers from Béziers (F) back to Zurich, where it landed at 19:10 hrs.

[2] small wingtip endplates

1.1.2 History of the flight

Before the flight back to Geneva, the pilot obviously decided to refuel. According to the statements of aircraft refuelling attendant B at approx. 19:45 hrs the pilot ordered "*Kraftstoff JET-A1*" by telephone.

Unlike the telephone conversations of air traffic control at Zurich airport, incoming and outgoing telephone calls made to and from the refuelling service of Jet Aviation Zurich AG were not recorded. The precise wording of the pilot's fuel order cannot therefore be established with certainty.

Aircraft refuelling attendant B then forwarded the order by radio to his colleague, aircraft refuelling attendant C. A third aircraft refuelling attendant D heard on his radio how aircraft refuelling attendant B gave the instruction to aircraft refuelling attendant C to refuel aircraft HB-LTC with JET A-1 fuel. Then aircraft refuelling attendant C drove tanker FL 7 to HB-LTC, which was parked in GAC Sector 1. According to his statements, he positioned the tanker with its right-hand side in front of the aircraft so that he could reach the filler caps on both wings using the hose affixed to that side of the tanker.

Then aircraft refuelling attendant C, still next to the tanker, began to complete the delivery note, while the pilot came up to him and indicated the desired quantity of fuel in English. The pilot gave him a credit card and aircraft refuelling attendant C then explained to him that after refuelling he would have to complete the transaction in the office. The pilot remarked that he had a slot[3]. Aircraft refuelling attendant C later stated that this gave him to understand that the pilot did not have much time. The aircraft refuelling attendant replied to the pilot that he would only need an additional two or three minutes.

Because it had started to rain shortly before refuelling, the pilot evidently withdrew into the aircraft after his conversation with aircraft refuelling attendant C. According to his partner, the pilot conducted a brief conversation with her from his mobile telephone during this phase. As the investigation showed, this telephone call took place between 19:50:06 and 19:51:28 hrs.

In the meantime, aircraft refuelling attendant C had connected HB-LTC to the tanker and then pumped 50 l of JET A-1 fuel into each of the two inboard main cells. The aircraft refuelling attendant later stated that he had not noticed markings or labels which described the permitted types of fuel for this aircraft, either on the tank seals or in the vicinity of the tank openings.

He then drove the tanker to the office, debited the credit card and returned it with the receipt and the delivery note to the aircraft. He presented the debit slip and the delivery note to the pilot for signature. In the process the aircraft refuelling attendant asked the pilot what aircraft type HB-LTC was. The pilot answered that his aircraft was a modified PA31. The aircraft refuelling attendant then entered "PA31" on the delivery note and then gave the pilot the carbon copy.

[3] ATC window for departure, arrival or entering an airway

At 20:08:44 hrs the pilot made radio contact with Zurich Clearance Delivery (ZRH CLD) air traffic control and received departure clearance with the instruction to change to the ZRH APR frequency for start-up clearance. The apron gave HB-LTC start-up clearance at 20:10:00 hrs. Three minutes and 50 seconds later the pilot requested taxi clearance and was then instructed to taxi to the holding point of runway 28. After the transfer to ZRH TWR at 20:15:02 hrs the pilot stated he was ready for take off at 20:17:30 hrs. A short time after this he was able to line up runway 28 and at 20:20:58 hrs ZRH TWR gave him take-off clearance.

According to witness statements, HB-LTC took off normally and went into a climb. In the region of runway intersection 28/16 and at an altitude of approx. 50 m AGL[4] the aircraft stopped climbing, maintained level flight briefly and began to descend slightly. At the same time, HB-LTC began to make a gentle right turn and overflew the woods to the north of runway 28. Because of this unusual flight pattern, the duty aerodrome controller[5] (ADC) at 20:22:08 hrs asked the pilot whether everything was normal: “Tango Charlie, normal operations?” The pilot replied in the negative: “(Ne)gative, Hotel Tango Charlie!”

In this phase, the aircraft began to make a left turn with a high bank angle and witnesses observed that the landing gear was lowered. At 20:22:21 hrs the pilot radioed that he was in an emergency situation: “Mayday, Mayday, Mayday, Hotel Tango Charlie”. During the first 90° of the turn, HB-LTC descended only slightly. After crossing the extended center line of runway 28 the aircraft increasingly lost height in the tight left turn. When the aircraft had almost completed the full turn, its bank attitude began to reduce. At a height of approx. 10 m AGL HB-LTC collided with the trees in a copse. The aircraft passed through the copse and came to rest upside down in the “Glatt” river. The pilot was fatally injured on impact.

Coordinates of the final position of the wreck: 682 700/256 700, elevation 420 m AMSL corresponding to 1378 ft AMSL[6].

National map of Switzerland 1:25000, sheet No. 1071, Bülach

[4] m AGL – metres above ground level

[5] air traffic controller of the air traffic control unit TWR

[6] ft AMSL – feet above mean sea level

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	1	-	-
Serious	-	-	-
Minor/None	-	-	

1.3 Damage to the aircraft

The aircraft was destroyed.

1.4 Other damage

There was damage to land and fields. Oil booms were put in place to protect the "Glatt" downstream of the accident site. According to information from the Office for Waste, Water, Energy and Air (*Amt für Abfall, Wasser, Energie und Luft* – AWEL) of the canton of Zurich, the resulting water pollution can be described as slight.

1.5 Personnel information

1.5.1 Pilot in command

Person:	Swiss citizen, born 1957
Licences:	Commercial pilot's licence, issued by the Federal Office for Civil Aviation, valid till 22.10.2000 Commercial pilot licence for multiengine airplane land and instrument airplane, issued by the Federal Aviation Administration (FAA) of the United States of America
Ratings:	Single-engine and multi-engine aircraft with reciprocating engine(s), flown by one pilot, with a maximum take-off mass of 5700 kg, equipped with flaps, variable pitch propeller and retractable landing gear. Type rating for Piper PA31/42, issued on the occasion of the IFR check on 24.5.00, valid till 24.5.01
Extensions:	Night flying, international radiotelephony certificate for visual flight rules (VFR)
Last IFR[7] check:	24.5.00, valid till 24.5.01

[7] IFR – instrument flight rules

Medical certificate:	12.4.2000, findings: fit without restrictions
Languages:	French: mother tongue
	English: good knowledge of spoken and written language
	German: school-level knowledge

1.5.1.1 Flying experience

Total:	Approx. 1119 h
On type:	Approx. 9 h
During the last 180 days:	Approx. 39 h, of which approx. 9 h on the type involved in the accident
Start of flight training:	1985

1.5.1.2 Piloting and personal characteristics

The pilot was described by acquaintances and passengers as serious, reliable and correct. On the occasion of the IFR check on 24.5.00 his piloting performance was described by appropriate experts on a scale of 1 – 4[8] as 2+ “marginal plus”.

1.5.2 Aircraft refuelling attendant B

Person:	German citizen, born 1955
Professional experience:	Employed since 1990 by Jet Aviation as aircraft refuelling attendant.
Pilot’s licences:	None
Languages:	German: mother tongue
	English: school-level knowledge
	French: no knowledge

1.5.3 Aircraft refuelling attendant C

Person:	German citizen, born 1957
Professional experience:	Two years service as soldier serving for a fixed period with the German Army, responsible for military helicopter refuelling.

[8] Marking system: 1 = not qualified, 2 = marginal, 3 = standard, 4 = high standard.

	Employed since 1990 by Jet Aviation as aircraft refuelling attendant.
Pilot's licences:	None
Languages:	German: mother tongue
	English: good knowledge of the spoken language
	French: good knowledge of the spoken language

1.6 Aircraft information

Manufacturer:	New Piper Aircraft Corporation
Aircraft type:	PA31-350 Navajo Chieftain modified to Panther II
Characteristics:	Twin-engine low-wing, entirely metal construction, with retractable landing gear in nose wheel configuration. The cockpit had two seats and the passenger cabin had six seats.
Serial number:	31-7952003
Year of manufacture:	1979
Export airworthiness certificate:	E361826, issued by the Federal Aviation Administration (FAA)
Airworthiness certificate:	Issued by the Federal Office for Civil Aviation on 24.5.2000, valid until revoked
Registration certificate:	Issued by the Federal Office for Civil Aviation on 28.3.2000
Authorised category:	Technical flying categories: VFR by day, VFR by night, IFR; B-RNAV[9]
Left engine:	Textron Lycoming Division, air-cooled, turbocharged reciprocating engine with six cylinders in opposed configuration, type TIO-540-J2BD, serial number L-8550-61A
Right engine:	Textron Lycoming Division, air-cooled, turbocharged reciprocating engine with six cylinders in opposed configuration, type LTIO-540-J2BD,

[9] B-RNAV – basic area navigation: a method of navigation which enables the aircraft to navigate on any desired flight path within the coverage of appropriate ground based navigation aids or within the limits of self-containded on-bord equipment, or a combination thereof.

	serial number L-1726-68A
Left propeller:	Hartzell, constant speed propeller, hydraulically operated, type HC-C4YR-2/FC 7663DB-6Q, serial number FH 740, year of manufacture 1995
Right propeller:	Hartzell, constant speed propeller, hydraulically operated, type HC-C4YR-2L/FJC 7663DB-6Q, serial number FH 718, year of manufacture 1994
Total flying hours:	Approx. 8387:30 h
Maintenance:	On 10.5.00 at 8380:48 hours of operation a 100 h check was carried out.
Examination of the Aircraft:	As the aircraft was imported from the USA and a license was sought for use in Switzerland for the first time, the Federal Office for Civil Aviation (FOCA) performed two technical examinations of HB-LTC on 8 March 2000 and on 15 May 2000. On the occasion of these examinations the FOCA identified various slight deficiencies. The seat belt system, however, was not identified as one of these.
Fuel:	AVGAS 100LL
Reserve flying time:	The aircraft was fully refuelled on 25 May 2000 in Zurich. For the flight to Béziers the engines, according to the aeroplane flight manual (AFM), consumed approx. 305 l of fuel. On 26 May 2000 in Béziers, the aircraft was refuelled with 107 l of AVGAS 100LL. The same consumption as for the outward flight can be assumed for the return flight to Zurich. So before the departure for Geneva, there was still approx. 220 l of AVGAS 100LL in the tanks, corresponding to a reserve flying time of approx. 1:40 h.
Mass and centre of gravity:	The maximum take-off mass of the aircraft was 3342 kg. With one person and approx. 320 l of fuel onboard, the mass and centre of gravity were within the permitted limits.

1.7 Meteorological information

1.7.1 General weather situation

Between a weak high centred over Poland and a trough extending from Biscay over the British Isles to Scandinavia, increasingly moist air was flowing from the south-west towards the Alps. The centre of the secondary low was over the English Channel. At the time of the accident, Switzerland was in the warm sector of the polar front associated with this low.

1.7.2 Weather at the time and place of the accident

Weather/cloud:	1 – 2/8 base at 5500 ft AMSL, 3 – 4/8 base at 7500 ft AMSL, 5 – 7/8 base at 9500 ft AMSL, light rain showers
Visibility:	10 km
Wind:	On the ground from 230° at 5 kt At 1700 ft AMSL from 230° at 8 kt At 2100 ft AMSL from 200° at 6 kt
Temperature/dew point:	21 °C/15 °C
Atmospheric pressure:	QNH 1013 hPa
Hazards:	None
Position of sun:	Azimuth: 295° Elevation: 17°

1.7.3 Aerodrome weather report

At the time of the accident the following METAR (aerodrome weather report) was in force:

261820Z 23005KT 9999 – SHRA FEW040 SCT060 BKN080 21/15 Q1013 TEMPO NSW

In clear text, this means: on 26 May 2000 at 18:20 UTC = 20:20 hrs local time, the following meteorological conditions were observed at Zurich airport:

Wind:	From 230° at a speed of 5 knots
Meteorological visibility:	Greater than 10 km
Precipitation:	Light rain showers
Cloud:	1-2/8 at 4000 feet above aerodrome elevation 3-4/8 at 6000 feet above aerodrome elevation 5-7/8 at 8000 feet above aerodrome elevation
Temperature:	21 °C
Dew point:	15 °C
Atmospheric pressure:	1013 hPa, pressure reduced to seal level, calculated using the values of the ICAO standard atmosphere
Landing forecast:	In the two hours following the weather observation, it was to be expected that no significant weather phenomena would occur for some time. The total time of this change would provisionally be less than

one hour.

1.7.4 Weather according to witness statements

During refuelling of HB-LTC on 26 May 2000, which with great probability took place between 19:45 and 20:00 hrs, showery to heavy rain was falling, according to several witnesses.

1.8 Aids to navigation

Not involved.

1.9 Communications

Radiocommunications between the pilot and the air traffic controllers from the various air navigation services took place within the normal framework. Transcripts of the radio conversations directly related to the accident flight are provided in Appendix 1.

1.10 Aerodrome information

1.10.1 General

UNIQUE Zurich Airport has three runways:

Runway 16/34 Dimensions 3700 x 60 m
Altitude of thresholds of runway 1390 ft/1386 ft AMSL

Runway 14/32 Dimensions 3300 x 60 m
Altitude of thresholds of runway 1402 ft/1402 ft AMSL

Runway 10/28 Dimensions 2500 x 60 m
Altitude of thresholds of runway 1391 ft/1416 ft AMSL

The reference altitude of the airport is 1416 ft AMSL and its reference temperature is 24.0 °C.

1.10.2 Runway equipment

Runways 14 and 16 are approved for CAT III B precision approaches.

No other runways are equipped for precision approaches.

1.10.3 Rescue and fire fighting services

The airport fire fighting service complies with Category 9.

1.11 Flight recorders

Not prescribed and not installed.

1.12 Wreckage and impact information

1.12.1 Accident site

The wreck of the aircraft was lying upside down in the river "Glatt". From the position of the wreckage it was apparent that the aircraft had first collided with the trees on the north-western side of the copse a few metres above the ground. Parts of the left wing were suspended in a fir tree and part of the right wing was suspended in the branches of a walnut tree. Snapped treetops and broken branches could be observed as far as the left bank of the stream. Most of the parts of the wreckage were scattered on the floor of the wood in the area of the flight path.

The deformation of the propellers indicated that both engines were stopped or turning only at slow speed when the blades of the propeller came into contact with obstacles in the path of the impact.

The landing gear was down.

1.12.2 Wreckage

The salvaged wreck was conveyed to Zurich airport and examined in detail. Among other things the following findings were established:

- All surfaces producing lift and all control surfaces were present.
- Visual inspection of the control columns, rudder pedals, deflection rollers, control cables and turnbuckles gave no indication of any malfunction of the controls.
- About 20 cm from the filler openings of the inboard main cells there were ochre-coloured fuel grade rating placards, on which black lettering proclaimed "CAUTION USE 100/130 GRADE FUEL OR HIGHER ONLY" (cf. photo in Appendix 2).
- It was possible to take fuel from the main filter of the left-hand fuel system and from the electric pumps of the left and right system respectively.
- Both tank selector switches were in the "INBD TANK ON" – inboard tank on - position. This setting connects the rearmost fuel tank in the wing (inboard main cells) to the respective engines.
- The crossfeed valve which connects the two fuel systems was closed and the left-hand fuel system was thus separated from the right-hand one.
- The fuel indicators for the inboard main cells were both between ½ and ¾ full.
- The power levers of both engines were towards the forward position, i.e. in the position for maximum boost pressure.
- Both propeller control levers were forward, in the position which corresponds to maximum speed and tending towards a low propeller blade pitch.

- The mixture control lever of both engines was found to be in the “full rich” position.
- The four magnetos of both engines were switched on.
- The electric pumps of both fuel systems were switched on.
- One spark plug had a broken electrode. Several spark plugs were coated with soot.
- The cowl flaps of the left-hand engine were closed. The position of the cowl flaps on the right-hand engine could not be determined.

1.13 Medical and pathological information

An autopsy was performed on the pilot’s body in the *Institut für Rechtsmedizin*, Zurich University, including chemical-toxicological tests. The corresponding reports state:

“The autopsy findings show that the 43-year old pilot (pilot’s name) died as a direct result of the flying accident. Cause of death was heart failure as a result of the dissection of the anterior interventricular branch of the left coronary artery. No pre-existing diseases of the internal organs relevant to the accident were to be found.”

“The chemical-toxicological tests we have carried out to date have revealed no foreign substances which may have had a negative effect at the time of the accident on the mental and/or physical functions of (pilot’s name).”

1.14 Fire

Fuel was released and ignited on impact of the aircraft. The fire was confined primarily to the parts of the aircraft protruding from the “Glatt” and to fuel and oil slicks which collected on the surface of the water. The airport fire-fighting service extinguished the fire after a few minutes.

1.15 Survival aspects

1.15.1 Rescue operations

Alerting of the airport fire fighting service by the aerodrome controller (ADC) took place immediately and rescue services were at the site of the accident after a short time. After fighting the fire caused by the impact, an opening was cut into the wreckage, because access into the aircraft via doors, emergency exits or windows was no longer possible.

The depth of water in the “Glatt” was between 70 and 100 cm at the site of the accident. The interior of the aircraft was not therefore completely flooded. The rescue services found the pilot’s body in the rear of the aircraft. This indicates that the pilot was still able to remove himself from the cockpit after the impact.

The emergency location transmitter (ELT) was triggered by the impact and was operating.

1.15.2 Causes of injuries

Since the aircraft was decelerated over a distance of approx. 50 m, the resulting g-forces were within a range which would in principle have been survivable. The safety belt system, consisting of a pelvic and shoulder belt, was being worn by the pilot (cf. also chapter 1.16.5). However, the retention mechanism of the shoulder belt was not functioning, so the pilot's upper body was flung against the control wheel as a result of the deceleration. The dissection of the anterior interventricular branch leading to heart failure, as revealed by the autopsy, is very probably attributable to this impact.

1.16 Test and research

1.16.1 Flight path

Since the accident flight lasted for only about one and a half minutes and the altitude of HB-LTC was not much more than 50 m AGL, none of the radar systems which monitor the airport area was able to record parts of the flight path. The GARMIN GNS 430 satellite navigation equipment found in the aircraft does not make any flight path recordings. It merely stores flight plans and certain settings in RAM with battery back-up[10]. In the present case it was not possible to read data from the equipment after the accident since the memory battery was no longer working. The flight path until the aircraft flew into the copse to the west of the river "Glatt" was reconstructed with the aid of witnesses' observations.

In order to establish accurately the configuration of the aircraft's collision with the obstacles in its path, the Zurich city police's Scientific Service *(Wissenschaftlicher Dienst* – WD) uses multi-image photogrammetry. This procedure makes it possible to reconstruct the final phase of the flight of the aircraft involved in the accident (cf. Appendix 3). In particular it was possible to establish that at the time of the first collision with the trees, the aircraft was at an altitude of about 10 m above ground level. The bank angle of the aircraft at that time was 12° - 13° to the left. Subsequently, the direction of movement of HB-LTC was inclined at approx. 4° downward. In view of the aircraft's final position, it must be assumed that as it flew through the copse, viewed in the direction of flight, it rotated approximately 180° left around its longitudinal axis. From the forensic viewpoint, this conclusion is backed up by the observation that a group of fir trees had branches stripped over a fairly long area against the direction of flight and bent in the direction of flight. After the tip of the right wing had been torn off on initial collision with the trees at the edge of the wood, the remaining stump of the right wing slid up along the tree trunks, which bent in the direction of flight. This unilateral contact caused the machine to rotate counter-clockwise around its longitudinal axis.

1.16.2 Fuel samples

The samples of fluid taken from the main filter of the left-hand fuel system and from the electric pumps of both systems were handed over to the WD for analysis. With the aid of gas chromatography-mass spectrometry, the volatile compo-

[10] RAM – random access memory: volatile read/write memory. The memory content is lost if the supply voltage is switched off.

nents of the samples were very accurately identified. The corresponding report states as follows:

1.16.2.1 Sample from the main filter of the left-hand fuel system

"On the basis of our analyses, the residual fluid from the left-hand fuel filter is a mixture of AVGAS 100LL and kerosene JET A-1. However, some of the highly volatile components of AVGAS have already evaporated.

The ratio of AVGAS 100LL to kerosene JET A-1 in the fluid from the fuel filter is approx. 35 – 45% by volume AVGAS 100LL and 65 – 55% by volume kerosene JET A-1."

1.16.2.2 Sample from the fuel pumps

"Both fluids are a mixture of AVGAS 100LL and kerosene JET A-1. However, some of the highly volatile components of AVGAS have already evaporated.

The ratio of AVGAS 100LL to kerosene JET A-1 in both fluids is approx. 60–80% by volume AVGAS 100LL and 40–20% by volume kerosene JET A-1."

1.16.3 Engines

The two Lycoming (L)TIO-540-J2BD engines of HB-LTC were dismantled and examined with a specialist from the Aerothermochemistry and Combustion Systems Laboratory of the Institute for Energy Technology of the Swiss Ferderal Institute of Technology Zurich (ETH). Among other things, the following points were established:

- The con-rods exhibited increasing brown discoloration from the plane of the propeller towards the rear. This discoloration is not unusual and is attributable to the fact that the rear cylinders of an air-cooled opposed cylinder engine are cooled less than the front combustion chambers. Therefore, as temperature increases, a thicker layer of oleo-resinous varnish is deposited on the con-rods. This varnish is responsible for the discoloration.
- The tops of the pistons examined showed no deformation or damage. On some there was a thin layer of soot.
- The cylinders examined exhibited no visible damage. Nor did the area of the inlet and exhaust valves exhibit any peculiar features.
- There were no indications of pre-existing defects.
- Apart from one spark plug with a broken electrode, no mechanical damage could be found which would point to "knocking" combustion. The reason for this is probably the short operating time of the engines with the fuel mix of AVGAS and JET A-1. It is to be assumed that the engines lost power quickly, because the fuel mixture being fed to them was hardly combustible any more. This is the case with a kerosene component in excess of 30%.

1.16.4 Instruments

Of the various instruments which were removed from the aircraft after the accident, only the tachometer from both engines, plus a multi-function instrument which indicates oil pressure, oil temperature and cylinder head temperature, were able to be analysed by the WD. The corresponding reports state:

1.16.4.1 Tachometer

"The instrument is externally intact. The arrangement of the pointers for the two engines, "Left and Right", is such that the pointers are positioned one above the other, with the "left" pointer turning directly above the dial with figures.

Because of this design, possible traces of pointer marks were to be expected only from the "left" pointer. The "right" pointer is too far above the dial for such traces to be found.

We found a bent mark in the "11 o'clock" area of the round end of the pointer. This corresponds to the balancing weight of the "left" pointer (fig. 1 top and bottom). This indicates a pointer position of practically "zero" rpm. We are unable to provide any information on the "right" pointer position at the time of impact, because of the reasons given" (reference to figure in the original).

1.16.4.2 Multi-function instrument for engine monitoring

"This triple-function instrument is also externally in good condition. We removed the cover with labelling for the investigation.

In the case of the "cylinder" temperature indication, we were able to detect white-coloured deposits at the edge of the dial, made by the white pointer. The deposits begin at a pointer position of approx. 260 °F and extend to the range of approx. 100 °F. Accordingly, at the time of the accident, the pointer was at approx. 260 °F (fig. 2 top and centre).

The first white pointer traces for the "oil" temperature indication are present as a horizontal strip in the approximate range of 150 °F. Other punctual colour traces can be detected in the approx. 50 °F range. It can therefore be assumed that the pointer was originally at a position of approx. 150 °F (fig. 2 top and bottom).

The pointer for oil pressure, "Oil PSI", can be freely rotated. Because of a defect, presumably as a result of the crash, it is no longer connected to the drive unit under the dial. No pointer traces are apparent. In forensic terms, there is therefore no starting point for an analysis of the pointer position at the time of the accident." (references to figures in the original).

1.16.5 Safety belt system

1.16.5.1 Investigation

The injuries which the pilot suffered indicate that protection by the safety belt system was inadequate. Therefore, the WD was instructed to analyse the belt system in detail. The corresponding report comes to the following conclusions:

"On the basis of the overall traces of evidence, on both the pelvic and shoulder belts, it must be assumed that the belt system was being worn at the time of the accident.

The stretch marks over the full length of the shoulder belt prove that the roller did not lock on impact, but unrolled as far as the end stop; the pilot was retained only when the entire belt had unrolled.

The fact that the belt roller did not lock is probably attributable to abrasions of the metal belt components."

1.16.5.2 Examination and Maintenance

As the aircraft was imported from the USA and a license was sought for use in Switzerland for the first time, the Federal Office for Civil Aviation performed two technical examinations of HB-LTC on 8 March 2000 and on 15 May 2000. On the occasion of these examinations the FOCA identified various slight deficiencies. The seat belt system, however, was not identified as one of these.

At the last 100 h check on 10 May 2000, according to the manager of the Airbase Ltd. maintenance company, the condition of the safety belts and the operation of the roller mechanism were checked. No parts of the belt system were replaced.

With reference to the belt system, the aircraft manufacturer's maintenance regulations (Navajo Chieftain service manual) contain the following instruction for a 100 h check: "Inspect seats, seat belts, security and condition of brackets and bolts". According to the maintenance company manager, no further aircraft manufacturer's regulations exist with regard to the maintenance of the belt system.

1.16.6 Determination of the fuel grade and fuel grade rating placards

1.16.6.1 General

In order to allow simple recognition of the grade of different fuels and to keep different types of fuel separate, the oil companies world-wide use the designation and colour system of the American Petroleum Institute (API)[11] for aviation.

In accordance with this system, at the time of the accident there were three grades of commercially available aviation gasoline (AVGAS) with the designation "AVGAS 80", "AVGAS 100" and "AVGAS 100LL" These three grades are distinguished by the following four characteristics:

a) Lean mixture rating

b) Rich mixture rating

c) Tetraethyl lead content

d) Colour

The AVGAS 100LL grade, for example, has a lean mixture rating of 100, a rich mixture rating of 130, is mixed with max. 2.0 ml tetraethyl lead per U.S. gallon and is died blue.

The lean mixture ratings of the three types are indicated on the respective fuel grade rating placards in white letters on a red background. Each type of AVGAS

[11] Cf. API Bulletin 1542: Airport Equipment Marking for Fuel Identification, sixth edition, 1996

has a different colour: AVGAS 80 is red, AVGAS 100 green and AVGAS 100LL – as already mentioned – is died blue.

The API designation and colour system also covers three types of kerosene used in civil aviation for operating turbine engines. On fuel grade rating placards, the types JET A, JET A-1 and JET B are indicated in white letters on a black background. All grades are supplied without added coloration. Their natural colour varies between colourless and slightly yellowish.

In order to prevent incorrect refuelling, the General Aviation Manufacturers Association (GAMA) some time ago introduced fuel designations and fuel grade rating placards based on the API designation and colour system[12]. The corresponding regulations specify, among other things, that fuel grade rating placards for aviation gasoline must be bordered in red and must include the text "AVGAS ONLY". The fuel grade rating placards for kerosene, on the other hand, must be bordered in black and must include the text "JET FUEL ONLY". By analogy, according to the GAMA specifications, the filler guns must also be painted either red (AVGAS) or black (kerosene).

1.16.6.2 Fuel grade rating placards on the aircraft

The requirements of FAR[13] 23.1557(c)1, which were in force at the time of certification of the PA31-350, specify that the word "FUEL" must be marked on or near the tank filler opening. In the case of reciprocating engine-powered aircraft, the minimum octane rating of the aviation gasoline to be used must also be specified. Identification by colour is not prescribed.

Since 7 September 1993 FAR regulation 23.1557(c) specifies that on reciprocating engine-powered aircraft the word "AVGAS" and the minimum octane rating of the aviation gasoline to be used must be indicated on or near the tank filler opening. In contrast, the filler openings of turbine-engine aircraft must be identified by the words "Jet Fuel".

At a distance of approx. 20 cm in the direction of flight from the filler openings of the inboard main cells, ochre-coloured fuel grade rating placards were applied, displaying the following words in black type "CAUTION USE 100/130 GRADE FUEL OR HIGHER ONLY" (cf. figure in Appendix 2).

The fuel grade rating placards affixed to the aircraft therefore corresponded to the regulations in force at the time of certification. However, they were relatively inconspicuous, since their colour did not stand out particularly from the white-painted wings.

1.16.7 Tank openings

The aircraft HB-LTC had modified tank openings. These had been modified using metal plates so that the maximum diameter was only 63.5 mm (2.5 inches). The

[12] Cf. GAMA Specification No. 3, Specification for Decal to Minimize the Misfueling of General Aviation Aircraft, issued: July 1, 1982

[13] FAR – Federal Aviation Regulations: FAA requirements for aircraft construction

purpose of the modification was to reduce the original tank openings with a diameter of 76 mm (3 inches) and therefore make it impossible to incorrectly refuel with kerosene. This conversion was based on service bulletin (SB) 797A, published by the aircraft manufacturer, Piper Aircraft Corporation, on 2 April 1985. On 1 September 1987 the aircraft manufacturer replaced SB 797A with SB 797B, which now described the modification as mandatory. On 2 November 1987, the FAA issued airworthiness directive (AD) FAA AD 87-21-01, which prescribed implementation of SB 797B within a period of one year. Consequently, the FOCA brought AD HB-231 into force on 16 December 1987; it contained the same modification.

The above-mentioned service bulletins (SB) and airworthiness directives (AD) were part of a programme implemented at that time by the aviation industry to prevent incorrect refuelling of aircraft. This programme also involved the oil companies in an effort to convert all systems used for overwing refuelling with kerosene to delivery nozzles with outside diameters from 67 to 75 mm.

The records on the maintenance of HB-LTC show no entry on the implementation of the above-mentioned modification. FAA AD 87-21-01 and SB 797A/SB 797B are described as “non applicable”. However, on the basis of the aircraft’s serial number, the cited instructions were applicable and were clearly also implemented, though they were not recorded in the aircraft’s maintenance record.

1.16.8 Refuelling equipment

1.16.8.1 Tanker vehicle

HB-LTC was refuelled with kerosene on 26 May 2000 from tanker vehicle FL 7. This vehicle is designed for overwing refuelling of aircraft with JET A-1. It bore the company logo of Jet Aviation Zurich AG and was partially painted in the colours of the fuel supplier, Shell. The sides and rear of the tanker bore fuel grade rating placards according to the API colour system , with “JET A-1” in white lettering on a black background (cf. figure in Appendix 4). These stickers were 10 x 38 cm and were well contrasting with the white background.

On the right-hand side, tanker FL 7 had a drum onto which the fuel hose was wound. At the end of the hose was a filler gun with a simple delivery nozzle, which had an outside diameter of 44 $\pm$ 0.5 mm and a length of 142 $\pm$ 2 mm (cf. figure in Appendix 5). The entire filler gun was unpainted and exhibited the natural colour of the materials used in its manufacture (silver grey/brass-coloured).

1.16.8.2 Delivery nozzle

After a series of accidents which occurred in England a few years ago because reciprocating engine-powered aircraft had repeatedly been incorrectly refuelled with kerosene, Jet Aviation Zurich AG modified the delivery nozzles of tanker vehicles which were used for overwing refuelling with JET A-1. These delivery nozzles were shaped so that they had an outside diameter of 67 mm.

However, since aircraft at Zurich airport with tank openings less than 67 mm in diameter also had to be refuelled with JET A-1, after about six months the filler guns were again fitted with a delivery nozzle with an outside diameter of approx. 45 mm.

At Jet Aviation Zurich AG it was possible, after the accident, to seize a modified delivery nozzle which was based on a metal pipe with an outside diameter of approx. 45 mm. In addition, at the end inserted into the tank opening, two metal bars approx. 50 mm long were welded onto it radially, giving the delivery nozzle a maximum outside diameter of 67.5 ± 0.5 mm (cf. figure in Appendix 5). Because of its dimensions, this modified delivery nozzle would not have been able to be inserted into the tank openings of HB-LTC (cf. figure in Appendix 5).

1.16.9 Refuelling procedure

1.16.9.1 General

At the time of the accident, the following practices were usual at Zurich airport for refuelling aircraft in general aviation:

- Refuelling orders were mostly placed by the respective crews, by telephone or by radio, with Jet Aviation Zurich AG. Only orders received by fax existed in written form.

- A form, "FUEL ORDER FORM – BETANKUNGSAUFTRAG", was provided for refuelling aircraft with tank openings without fuel grade rating placards.

- After refuelling, the person ordering the fuel was issued with a delivery note or a receipt.

1.16.9.2 Receipts for the HB-LTC fuel order

Jet Aviation Zurich AG used light-brown receipt forms which were completed by the aircraft refuelling attendant concerned and signed by the person receiving the fuel. In addition to other fields, this form included two sections containing information on the fuel supplied. The upper section noted the physical characteristics or the fuel (density, temperature and quantity), whilst the lower part was used to draw up the amount billed. The fuel grades JET A-1 and AVGAS 100LL were listed in two separate fields. Depending on the type of fuel ordered, either the "JET A-1" fields or the "AVGAS 100LL" fields were completed.

On May 25 2000, after aircraft refuelling attendant A had refuelled HB-LTC with 372 l of AVGAS 100LL, he handed the pilot a receipt on which he had entered, among other things, the following information (*Handwritten entry* identified by different font):

- Field "AVGAS 100LL": Density *705, 16* °C, Quantity in figures lt *372*

- Billing field on the line "AVGAS 100LL": *372* Lt. à Fr. *1.06*, Fr. *394.30*

On the same receipt, the pilot completed the following items (*Handwritten entry* identified by different font):

- Field "Customer": *LEMANAiR Executive*

- Field "I acknowledge receipt of the above quantities Signature": *Signature*

A similar receipt form exists for the refuelling of HB-LTC with 100 l of JET A-1 kerosene on 26 May 2000; among other things it bears the following entries by aircraft refuelling attendant C (*Handwritten entry* identified by different font):

- Field "JET A-1": Density *795, 24* °C, Quantity in figures lt *100*
- Billing field on the line "JET A-1": *100* Lt. à Fr. *1.44*, Fr. *144.-*

Field "JET A-1" bears the black stamp "VERZOLLT" (duty paid) in characters 6 mm high.

On the same receipt, there are the following items completed by the pilot (*Handwritten entry* identified by different font):

- Field "Customer": *LEMANAiR Executive, GENEVA Airport*
- Field "I acknowledge receipt of the above quantities Signature": *Signature*

1.16.10 Training of refuelling personnel

As the investigation showed, aircraft refuelling attendants A and C from Jet Aviation AG, who refuelled HB-LTC in Zurich, had been trained in a comparable way:

Among other things, the training included operation of the different tanker vehicles for overwing refuelling and extended to the operation of the pressurised refuelling system used mainly for commercial aircraft. A sort of apprenticeship system was in place: the activity of a new aircraft refuelling attendant was followed and monitored for a few days by an experienced colleague. According to information from Jet Aviation Zurich AG all employees used on aircraft refuelling had taken part in a course on the transport of dangerous goods.

With regard to the problem of incorrect refuelling, both refuelling attendants stated that they had been instructed about the different grades of fuel and their identification by means of colours. In order to distinguish between reciprocating and turbine engine-powered aircraft, the following aids to distinguishing them were given to refuelling personnel: the engine housings of reciprocating engines are generally squarer than the housings of turboprops and the propellers of reciprocating engine-powered aircraft cannot be turned easily by hand, unlike those with turboprop engines which have no perceptible compression resistance.

There was no indication that the technical knowledge of the refuelling personnel was ever verified by a capability test. Nor did any systematic training about different aircraft types and their propulsion systems take place.

It was further established that the fuel supplier's regulations applicable to refuelling were available only in English.

1.17 Organisational and management information

1.17.1 Lemanair Executive SA

Lemanair Executive SA is an operator which organised business flights. At the time of the accident, HB-LTC was the company's only aircraft.

On 9 November 1999, the Federal Office for Civil Aviation (FOCA) suspended the operating licence for commercial transport of persons and goods, since at that time the only aircraft – a Piper PA34 Seneca – had been sold. After Lemanair Executive SA had acquired the aircraft HB-LTC, the company lodged an application for the granting of an air operator certificate (AOC) as a prerequisite for the reinstatement or renewal of the operating licence. The FOCA informed the applicant on 20 April 2000 that the documentation it had submitted would not be able to be checked before the end of May 2000. The FOCA also informed Lemanair Executive SA that a date for laying down the further procedure for reinstatement or renewal of the operating licence would be proposed to it before the end of May 2000. At the time of the accident, therefore, aircraft HB-LTC was only licensed for private carriage.

According to the Lemanair Executive SA documents found in the aircraft, the accident flight was a positioning flight.

1.17.2 Jet Aviation Zurich AG

1.17.2.1 Refuelling service

At the time of the accident Jet Aviation Zurich AG operated a maintenance service for aircraft at Zurich airport, with an associated refuelling service. Jet Aviation Zurich AG was a licensee of the fuel supplier, Shell.

According to information from Jet Aviation Zurich AG the activities of the refuelling service was based on the Shell guidelines and on the “Guidelines for Aviation Quality Control and Operating Procedures for Joint into-plane Fuelling Services”.

The refuelling service was headed by a refuelling manager, who managed the activities of the aircraft refuelling personnel. The individual employees worked in shifts and were employed on the refuelling of commercial aircraft (pressurised refuelling) and on refuelling general aviation aircraft (overwing refuelling).

1.17.2.2 Quality assurance

Jet Aviation Zurich AG had an internal quality assurance system. No internal company audits of the refuelling service by this department are available.

No documentation was found to indicate that the fuel supplier Shell had checked or audited the refuelling service of Jet Aviation Zurich AG.

1.17.3 Federal Office for Civil Aviation

1.17.3.1 Instructions and regulations

According to information from the Federal Office for Civil Aviation, no instructions or regulations governing the training of aircraft refuelling personnel exist. In particular no requirements regarding knowledge or the content of training are laid down. As the FOCA explained, the refuelling companies are responsible for training.

On FOCA’s side, there are no regulations on the marking of aircraft with fuel grade rating placards. The only basis in this regard is the Federal Aviation Regulations.

At the time of the accident there were no FOCA instructions or regulations concerning colour identification of filler guns. After the accident a corresponding directive was adapted (cf. chapter 4.2.2).

The dimensions of delivery nozzles on filler guns and the dimension of tank openings are not covered by FOCA directives.

1.17.3.2 Inspections

The Federal Office for Civil Aviation is responsible for the inspection of refuelling companies.

Prior to the accident with HB-LTC on 26 May 2000 the refuelling operation of Jet Aviation Zurich AG was never inspected by the FOCA. Only after the accident, on 22 January 2001, did an inspection of the fuel system take place by a process system manager from the FOCA.

1.17.3.3 Examination of the aircraft

The Federal Office for Civil Aviation is responsible for the licensing and examination of aircraft.

As the aircraft was imported from the USA and a license was sought for use in Switzerland for the first time, the Federal Office for Civil Aviation performed two technical examinations of HB-LTC on 8 March 2000 and on 15 May 2000. On the occasion of these examinations the FOCA identified various slight deficiencies. The seat belt system, however, was not identified as one of these.

1.18 Additional information

1.18.1 Capacity and utilisation of the tank system of the PA31-350

The fuel system of the aircraft type PA31-350 consists of two independent units which guarantee that each engine has its own fuel supply. If necessary, the two systems can be linked via a crossfeed valve, so that both engines are supplied from one tank system.

Each of the two tank systems built into the wings consists of one main tank located towards the fuselage (inboard main cell) and one (auxiliary) tank located further out (outboard auxiliary cell). The inboard main cells each have a capacity of 212 l, with a useable volume of 200 l. The outboard auxiliary cells each have a capacity of 151 l and their useable volume is 144 l. Thus the maximum fuel capacity of the PA-31-350 in the configuration described is 726 l, of which a maximum 688 l can be used.

The checklists of the PA31-350 Chieftain modified to Panther II specify that the engines must be supplied with fuel from the main tanks (inboard main cells) from start-up to the transition to cruising and from the start of a descent to shutdown. When cruising, the aeroplane flight manual (AFM) recommends using the outboard auxiliary cells first if the aircraft's centre of gravity is towards the rear. This tends to be the case when the aircraft is fully loaded.

1.18.2 Externally similar aircraft types

Several aircraft types in general aviation are available in a version with reciprocating engines and in a turbine engine-powered version. Since the different ver-

sions are generally almost identical in terms of the airframe and wing units, the types with different propulsion systems resemble each other. The PA31-350 Navajo Chieftain modified to Panther II which was involved in the accident is externally similar to the type PA31T Cheyenne from the same aircraft manufacturer. The Cheyenne series, unlike the Navajo/Chieftain series, is powered by turboprop engines, which require kerosene.

In comparison with other two-engine types of comparable size, the PA31-350 Navajo Chieftain modified to Panther II was rather seldom encountered in Switzerland.

2 Analysis

2.1 Technical aspects

2.1.1 Fuel mixture and failure of the engines

The aircraft HB-LTC departed from Zurich on 25 May 2000 fully fuelled with 726 l AVGAS 100LL and reached Béziers (F) about two hours later. If one assumes that the pilot operated the aircraft in accordance with the manufacturer's guidelines, the engines were operated with fuel from the inboard main cells from start-up to transition to cruising and from the start of the descent until shut down after landing. Since the aircraft was rather heavily loaded with eight people and luggage and had a centre of gravity towards the rear, it may further be assumed that the pilot selected the outboard auxiliary cells whilst cruising.

Using the flight profiles and consumption values of the AFM as a basis, about 305 l of fuel were required for the entire flight from Zurich to Béziers. Some 200 l would have been used in the cruising phase, while the engines were being fed from the outboard auxiliary cells. The remaining 105 l or so were taken from the inboard main cells, given the above-mentioned considerations.

Both the instructions in the AFM and the circumstance that the amount of fuel taken onboard in Béziers, 107 l, did not correspond to a round monetary amount, indicates that the pilot had the part-empty inboard main cells refuelled with this quantity. For the return flight, therefore, he had full main tanks and outboard auxiliary cells with approximately 50 l of fuel in each of them.

For the return flight from Béziers to Zurich it can be assumed that the first phase of the flight up to the transition to cruising again used the inboard main cells. Since each of the outboard auxiliary cells still contained about 40 l of useable fuel, it is highly probable that these were selected for part of the cruising phase. If the pilot flew on the outboard tanks until they were virtually empty and then switched to the inboard main cells, after landing in Zurich there would still be some 100 l in each of the main tanks and about 10 l in each of the outboard auxiliary cells.

After the incorrect refuelling in Zurich, when 50 l of JET A-1 kerosene was pumped into each of the inboard main cells, there was accordingly a mixture of approx. two parts AVGAS to one part JET A-1 in these tanks. How quickly these two components mixed together after refuelling remains an open question. In view of the higher specific gravity of kerosene compared with aviation gasoline, however, it can be assumed that at the lowest point in the tank, from which fuel was drawn off, there would tend to be a mixture with a higher kerosene component. The aviation gasoline still in the fuel lines, filter and pumps clearly made it possible for the engines to be started and for the aircraft to taxi for take-off. Shortly after take-off, this residue of useable AVGAS was consumed and the engines were only receiving fuel with at least 33% by volume of JET A-1 kerosene. This value is consistent with the fuel samples taken after the accident, which had a proportion of 20 – 40 and 55 – 65 percent by volume of kerosene, respectively.

As already stated in chapter 1.16.3, such a mixture was hardly combustible in the petrol engines, and this led to a massive and rapid drop in power and complete failure of the engines. Because of the symmetry of the two fuel systems, the loss

of power to both engines very probably took place more or less simultaneously, as also indicated by the fact that after the accident both propellers were found to be low-pitch. The failure of only one engine initially very probably caused the pilot to initiate an emergency procedure for a single-engine climb. This engine inoperative procedure provides for the propellers on the stopped engine to be feathered, in order to minimise wind resistance.

2.1.2 Safety belts

The failure of the retention mechanism of the shoulder belts transformed an accident which might possibly have been survivable into one with a fatal outcome.

The abrasions on the metal components of the belt system, which prevented the shoulder belt from functioning correctly, constitute contamination of the mechanism due to normal operation. The existing maintenance regulations are possibly too vague, or the mechanic responsible for maintenance work was not aware that the manufacturer's instructions "inspect (...) seat belts, (...)" also included cleaning the retention mechanism.

On the occasion of the technical examination of the aircraft by the Federal Office for Civil Aviation the malfunctioning of the seat belts was not established.

2.2 Risk factors

2.2.1 Delivery nozzles

The trial carried out by Jet Aviation Zurich AG a few years ago to prevent incorrect refuelling by means of technical measures (cf. chapter 1.16.8.2) was terminated after only a few months. Since the delivery nozzles in use at the time, with an outside diameter of 67 mm, also had to be used to pump kerosene into aircraft which had tank openings with smaller inside diameters, delivery nozzles with an outside diameter of approximately 45 mm were brought back into use. These relatively narrow delivery nozzles constituted a risk factor, since from a technical viewpoint they allowed HB-LTC to be refuelled, despite the fact that its tank openings had an inside diameter reduced to 63.5 mm (2.5 inches) by metal plates. It is striking what unfavourable effects resulted from the lack of standardisation of filler openings and delivery nozzles.

2.2.2 Training of refuelling personnel

The lack of technical safeguards relating to refuelling equipment and the multiplicity of aircraft, some of which have different types of propulsion despite having a similar airframe, appear to indicate that systematic training of aircraft refuelling personnel is essential. In the present case, both adequate instruction of the personnel concerned and regular checks and refresher courses were lacking. The circumstance that aircraft refuelling attendant C, despite many years' experience, did not identify the propulsion system of HB-LTC, or rather associated the modification of the aircraft with a conversion to turboprop operation, indicates both a lack of appropriate training and insufficent sensibilisation of the person involved with regard to this kind of problem.

The fact that the regulations in force and the applicable manuals were available only in English may have made it more difficult for refuelling personnel to assimilate the knowledge they lacked through independent study.

One constricting factor is that at the time of the accident no Federal Office for Civil Aviation directives or regulations were in existence in relation to the training and qualification of aircraft refuelling personnel.

2.2.3 Quality assurance and inspections

There are no obligatory regulations in relation to the above-mentioned deficiencies. Some of the risk factors may have been recognised and eliminated if quality control measures had been implemented. Neither the responsible offices of Jet Aviation Zurich AG nor the fuel supplier Shell identified the deficiencies. The Federal Office for Civil Aviation did not carry out inspections of the refuelling operations of Jet Aviation Zurich AG prior to the accident.

2.3 Operational aspects

2.3.1 Ordering of the fuel

Since the incoming and outgoing telephone conversations to and from Jet Aviation Zurich AG are not recorded, the precise wording of the fuel order cannot be established with any certainty.

In view of the fact that the pilot was only authorised to fly reciprocating engine-powered aircraft and that his mother tongue was French, it appears improbable that he literally ordered *"Flugpetrol*" (kerosene), *"Kerosen*" (kerosene) or "Jet Fuel". It was more conceivable that he communicated in English and used the neutral term "fuel". It is also conceivable that aircraft refuelling attendant B, who took the order, interpreted this term "fuel" as "jet fuel" and communicated the order to aircraft refuelling attendant C accordingly. A third aircraft refuelling attendant listened in on the radio to this order to refuel HB-LTC with JET A-1 fuel.

2.3.2 Refuelling procedure

During the refuelling operation, there would have been several opportunities both for aircraft refuelling attendant C and for the pilot to rectify the misunderstanding which had occurred when the fuel was ordered.

Aircraft refuelling attendant C apparently did not realise that HB-LTC was an aircraft powered by two reciprocating engines. In particular the winglets, which are nowadays actually frequently associated on modern general aviation aircraft with turboprop engines, clearly reinforced his assumption that the PA31-350 had been converted to turboprop propulsion. Since the type PA31-350 Navajo Chieftain modified to Panther II is encountered only rarely in Switzerland and since HB-LTC – apart from its stopover on 24/25 May 2000 – had never visited Zurich airport, it is understandable how this misconception might have occurred.

The fuel grade rating placards required by FAR were affixed approximately 20 cm forward of the tank openings for the inboard main cells, in the direction of flight. Aircraft refuelling attendant C pumped 50 l of JET A-1 kerosene into each of these tank openings. However, the colour of these did not stand out very well from the rest of the wing, and this explains why they were also not noticed by aircraft refuelling attendant A, who refuelled the aircraft on 25 May 2000.

For his part, the pilot obviously did not realise that he was receiving a different grade of fuel from the one he needed. The fuel grade rating placards on the tanker vehicle were very probably not highly visible to him, since during the refuelling operation he remained near the aft door or inside the aircraft. The tanker, however, was in front of the nose of HB-LTC. It is possible that the rain shower at this time or the telephone conversation with his partner caused him to remain inside the aircraft during refuelling of the aircraft.

When the pilot received the receipt for the supply of 100 l of JET A-1 kerosene, he signed it and did not notice the error. Probably the pilot was under some time pressure during this phase.

2.3.3 Accident flight

If one compares the departure of HB-LTC on 25 May 2000 with the departure of the accident flight, the following points can be established with regard to the chronology:

Procedure	Departure on 25 May 2000		Departure on 26 May 2000	
	Time [h:min:s]	Time difference [min:s]	Time [h:min:s]	Time difference [min:s]
Start-up clearance	08:18:42		20:10:00	
Ready to taxi	08:26:25	7:43	20:13:50	3:50
Taxi clearance	08:26:28	7:46	20:14:20	4:20
Ready for take-off	08:32:01	13:19	20:17:30	7:30
Take-off clearance	08:45:27	26:45	20:20:58	10:58

It is evident that in the case of the accident flight the interval between start-up clearance and indicating readiness to taxi and take off was clearly shorter than for the flight to Béziers (F) on 25 May 2000. The difference cannot be exclusively attributed to the fact that passengers were onboard during the first flight, since the safety belt and passenger instruction procedures were undoubtedly concluded before the request for start-up clearance. It may possibly indicate some time pressure, to which the pilot was subject on 26 May 2000.

On 25 May 2000, five minutes and 33 seconds elapsed between the taxi clearance and indicating readiness for take-off, whereas the pilot needed only three minutes and 10 seconds on 26 May 2000. In both cases it was necessary to taxi about 250 m to the holding point of runway 28 and complete preparations for take-off. As the passengers on the flight to Béziers later explained, both on 25 May 2000 and before the return flight on 26 May 2000, the pilot had in each case run up the engines first. Since no-one noticed such an engine check before the accident flight and the time for such a procedure seems rather short, it must be assumed that the engines were not run up. Such an engine check probably

would have provided an opportunity to discover the refuelling error while the aircraft was still on the ground.

The shorter time difference indicating readiness for departure and take-off clearance during the accident flight, however, was outside the pilot's control. Either traffic was lighter on the evening of 26 May 2000 than on the morning of 25 May 2000 or enroute clearance was available earlier for the accident flight. In any event, HB-LTC was able to be inserted into the traffic immediately on 26 May 2000. It is possible that if the waiting time had been longer, the engines might have failed on the ground, after the kerosene had made its way into the fuel lines.

Shortly after the take-off roll, however, this must have been the case: the engines were now being supplied with a mixture of JET A-1 and AVGAS 100LL, which was hardly combustible in view of the mixture ratio. On the basis of the progress of the flight observed by witnesses, it must be concluded that the engines continued to provide reduced power for a few seconds. This fact may have induced the pilot not to initiate an emergency landing on the remaining section of the runway or in the direction of the runway to the west of the aerodrome perimeter. Instead, he first prepared to turn right and then began a 180° left turn, very probably with the intention of landing on runway 10.

During this turn both engines failed completely, or rather the power they were still providing was no longer sufficient to maintain level continuation of the turn, at which point the pilot was no longer able to avoid collision with the obstacles in his path. The bank attitude of the aircraft at this time was 12° - 13° to the left. This low bank angle indicates that control had not been lost (a stall) before the aircraft flew into the trees.

2.4 Summary of the chain of events

Like most aircraft accidents, the accident to HB-LTC is not the result of a single cause. Three factors can be found which allowed the accident to happen because they led to latent failures and hence to potential risk:

- Absent or incomplete regulations for training refuelling personnel and for the refuelling of aircraft and for the technical equipment necessary for refuelling aircraft; this allowed corresponding shortcomings.

- The decision of the refuelling company to use delivery nozzles for kerosene with an outside diameter of less than 67 mm made refuelling of HB-LTC technically possible.

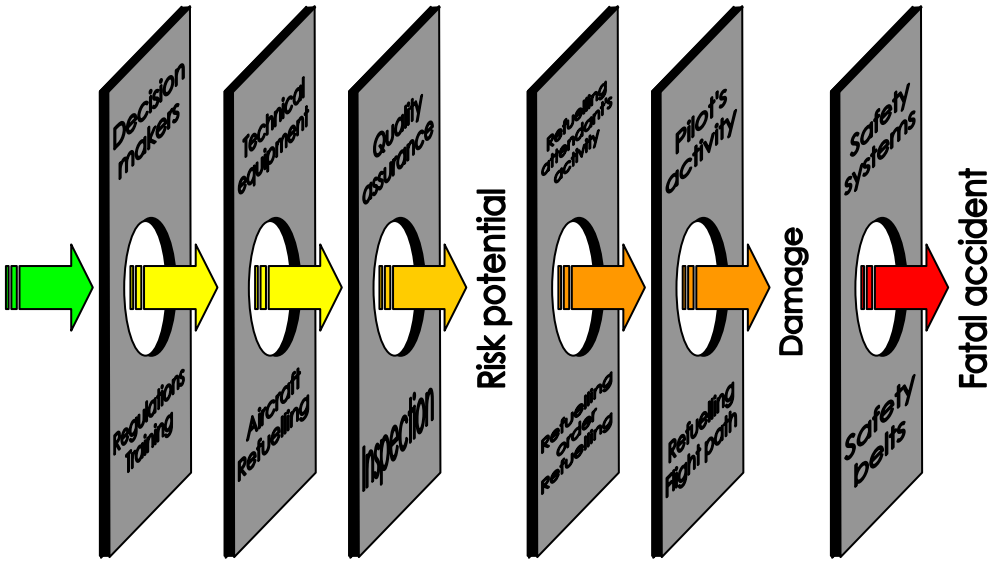
- The quality assurance measures of the refuelling company and the Federal Office for Civil Aviation were inappropriate or non-existent, and at the least ineffectual.

The potential risk created in this way was now associated with the human failure of the refuelling personnel and the pilot:

- When the fuel was ordered, a misunderstanding arose which could have been rectified by aircraft refuelling attendant C recognising the engines used on HB-LTC or the fuel grade rating placards on the aircraft.

- The pilot, for his part, did not recognise the fuel grade rating placards on the tanker vehicle FL 7 or the incorrect type of fuel on the receipt, which he signed.

The failure of the safety belts resulted in the pilot being fatally injured.



3 Conclusions

3.1 Findings

- The pilot was in possession of a valid pilot's licence.
- There is no indication that the pilot's state of health during the accident flight was impaired in any way.
- The mass and centre of gravity of the aircraft were within permitted limits.
- On 25 May 2000 between 07:20 and 07:30 hrs aircraft HB-LTC was refuelled at Zurich airport by refuelling attendant A from Jet Aviation Zurich AG with 372 l of AVGAS 100LL.
- After the refuelling operation, the pilot signed the receipt, which referred to 372 l aviation gasoline AVGAS 100LL.
- On 26 May 2000 between 15:35 and 15:45 hrs the aircraft was refuelled in Béziers (F) with 107 l of AVGAS 100LL.
- The statement of refuelling attendant B from Jet Aviation Zurich AG was: *"Er fragte mich, ob er Kraftstoff Jet A-1 haben könne".*
- Incoming and outgoing telephone calls at Jet Aviation Zurich AG refuelling service were not recorded.
- According to the statement by refuelling attendant C, aircraft refuelling attendant B gave aircraft refuelling attendant C the instruction, over the radio, to refuel aircraft HB-LTC with JET A-1 fuel.
- During the refuelling operation between 19:45 and 20:00 hrs rain showers or heavy rain was falling.
- According to the statements by aircraft refuelling attendant C the pilot was inside the aircraft during refuelling.
- Between 19:50:06 and 19:51:28 hrs the pilot made a call from his mobile telephone.
- On 26 May 2000 between 19:45 and 20:00 hrs refuelling attendant C from Jet Aviation Zurich AG pumped 50 l of JET A-1 kerosene into each of the two main tanks (inboard main cells) of aircraft HB-LTC.
- After the refuelling operation, the pilot signed a receipt which referred to 100 l of JET A-1 kerosene.
- At 20:10:00 hrs the pilot was given start-up clearance.
- At 20:13:50 hrs the pilot requested taxi clearance.
- At 20:17:30 hrs the pilot stated he was ready to take off.
- At 20:20:58 hrs the pilot received take-off clearance.

- Immediately after take-off, HB-LTC ceased climbing and began a 180° turn to the left.

- The marks on the propellers and the analysis of the tachometer show that the engines were providing little or no power when the aircraft struck the first obstacles in its path.

- HB-LTC finished upside down in the river "Glatt", the water level of which at that time was between 70 and 100 cm.

- At the time of the accident, the pilot was wearing both pelvic and shoulder belts.

- The retention mechanism of the shoulder belt did not function, because it was contaminated by abrasion of the metal components of the belt system.

- The investigation of the airframe gave no indication of pre-existing defects which might have contributed to the accident.

- The aircraft was licensed for non-commercial use.

- Approximately 20 cm from the filler openings of the inboard main cells there were ochre-coloured fuel grade rating placards, with black lettering reading "CAUTION USE 100/130 GRADE FUEL OR HIGHER ONLY" (cf. figure in Appendix 2).

- Tanker vehicle FL 7, from which HB-LTC was refuelled with JET A-1 kerosene, was provided with black fuel grade rating placards with "JET A-1" in white lettering.

- Aircraft HB-LTC had modified tank openings, the maximum diameter of which was 63.5 mm (2.5 in).

- The filler gun which was used to refuel HB-LTC with JET A-1 kerosene was not painted and had a delivery nozzle with an outside diameter of 44 $\pm$ 0.5 mm.

- Jet Aviation Zurich AG, at the time of the accident, had at least one delivery nozzle which was modified in such a way that, because of its maximum outside diameter of 67.5 $\pm$ 0.5 mm, it would not have been able to be inserted into the tank openings on HB-LTC.

- After the accident both tank selector valves were found to be in the "INBD TANK ON" – inboard tank on position.

- Apart from one spark plug with a broken electrode, no mechanical damage could be found on the engines which would indicate 'knocking' combustion.

- The analysed fluid samples from the aircraft's fuel system, together with combustion calculations, lead to the conclusion that at the time of the accident the inboard main cells each contained approx. 100 l of AVGAS 100LL and about 50 l of JET A-1 kerosene.

- The refuelling personnel concerned had not been made systematically acquainted with different aircraft types and their propulsion systems.

- The Federal Office for Civil Aviation never inspected the refuelling operation of Jet Aviation Zurich AG before the accident.

- Up to the time of the accident, the Federal Office for Civil Aviation had not issued any regulations on training or qualification of refuelling personnel.

- Up to the time of the accident, the Federal Office for Civil Aviation had not issued any regulations on the dimensions and design of filler guns, nozzles and filler openings on aircraft.

- Up to the time of the accident, the Federal Office for Civil Aviation had not issued any regulations on the marking of filler guns and filler openings for fuel on aircraft.

3.2 Causes

The accident is attributable to a collision with obstacles after the failure of both engines. The two reciprocating engines failed because the aircraft was refuelled in error with JET A-1 kerosene instead of AVGAS 100LL aviation gasoline.

The investigation established the following causal factors for the accident:

- A misunderstanding occurred when the fuel was ordered.
- The refuelling attendant concerned did not notice the fuel grade rating placards attached to the aircraft.
- The refuelling attendant concerned did not realise that the aircraft was equipped with reciprocating engines.
- The pilot did not notice the fuel grade rating placards on the tanker vehicle.
- The pilot did not realise the incorrect refuelling on the receipt for the fuel provision.

The following factors allowed or favoured the occurrence of the accident:

- The delivery nozzle on the filler gun was of an outside diameter which allowed the aircraft involved in the accident to be refuelled.
- The level of training and knowledge of the refuelling personnel concerned was inadequate.
- The Federal Office for Civil Aviation never inspected the refuelling operation before the accident.
- Up to the time of the accident, the Federal Office for Civil Aviation had issued no regulations on the training of refuelling personnel, the size of delivery nozzles and tank openings on aircraft or on the identification of filler guns and tank openings.

The following points may have exacerbated the outcome of the accident:

- The pilot decided on an about turn which brought him onto a collision course with obstacles.
- The retention mechanism of the safety belt was not working.

4 Safety recommendations and safety actions taken

4.1 Safety recommendations

4.1.1 Regulations and instructions for refuelling aircraft

4.1.1.1 Safety deficiency

The accident investigation determined that regulations concerning the following aspects were incomplete or completely absent:

- Training and qualification of refuelling personnel
- Dimension and design of delivery nozzles, filler guns and filler openings in aircraft as a function of the grade of fuel
- Marking and colour system for indicating the filler openings on aircraft in relation to the grade of fuel.

4.1.1.2 Safety recommendation 2003-1

The Federal Office of Civil Aviation should examine and revise the existing regulations and instructions on refuelling aircraft.

4.1.2 Harmonisation of refuelling equipment and labelling systems

4.1.2.1 Safety deficiency

The accident investigation determined that the dimensions and design of delivery nozzles and fuel tank filler openings on aircraft are not always compatible. In the case of this accident, this lack of harmonisation made incorrect refuelling possible in technical terms.

4.1.2.2 Safety recommendation 2003-2

The Federal Office of Civil Aviation should take measures which ensure that incorrect refuelling is no longer possible in technical terms.

4.1.3 Improvement of safety belt systems

4.1.3.1 Safety deficiency

The accident investigation determined that an important component of the safety belt system failed.

4.1.3.2 Safety recommendation 2003-3

The Federal Office of Civil Aviation should draw up measures which improve the functioning of safety belt systems.

4.2 Safety actions taken

4.2.1 Jet Aviation Zurich AG

Jet Aviation Zurich AG took several measures after the accident to prevent incorrect refuelling:

- The filler guns on tanker vehicles for JET A-1 kerosene were equipped with delivery nozzles which have a diameter of at least 67 mm.
- In order to refuel aircraft which have tank openings with an inside diameter of less than 67 mm, a narrower delivery nozzle may be fitted to the filler gun. The storage location of this narrower delivery nozzle is secured by a brake interlock system so that the tanker can only be driven again when the broader delivery nozzle is again fitted and the narrower one is stored in its compartment.

4.2.2 The Federal Office for Civil Aviation

After the accident, the Federal Office for Civil Aviation added the following paragraph to the directive on construction and maintenance of fuel installations on aerodromes:

"5.3.3. In order to prevent the risk of incorrect refuelling of aircraft, the nozzle valves (filler guns) on tank systems and refuelling vehicles must be identified as follows – as per the international standards:
- AVGAS = Red
- JET A-1 = Black
- MOGAS = Green"

Berne, 16 June 2003 Aircraft Accident Investigation Bureau

Appendix 1

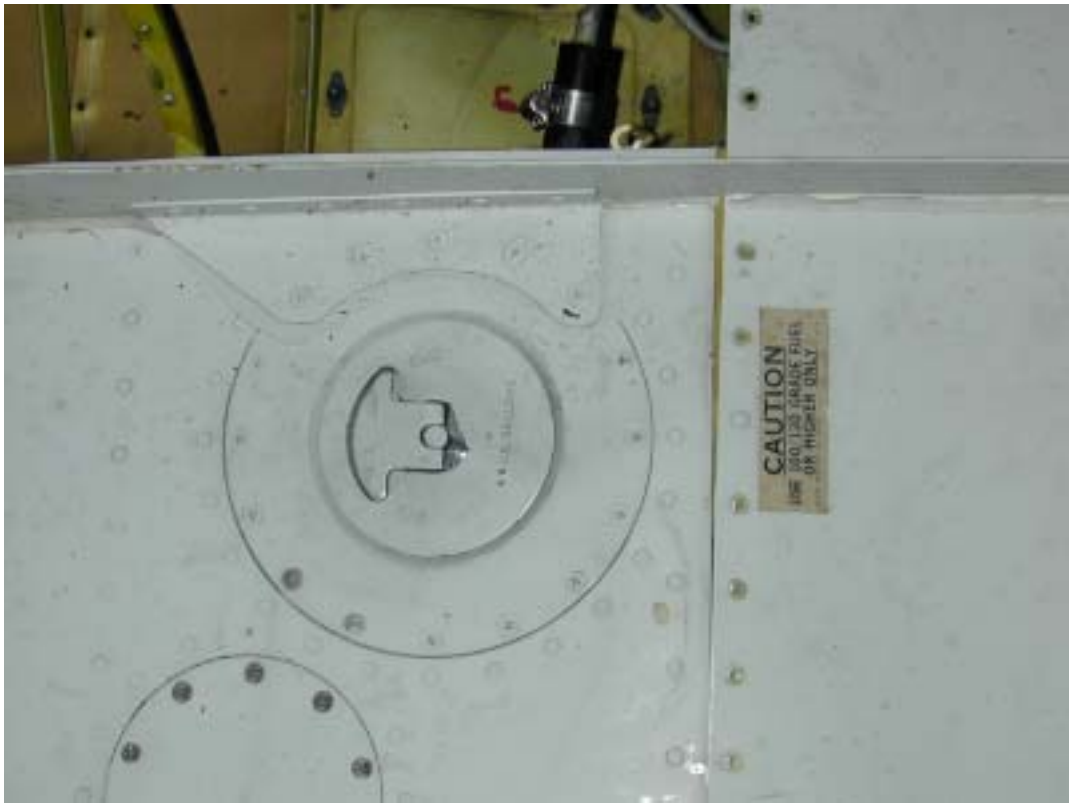
Transcript of the of the radio conversations between the pilot of HB-LTC and Zurich Air Traffic Control Clearance Delivery (CLD), Apron (APR) and Tower (TWR) on 26 May 2000.

From	To	Time (UTC)	Communication
LTC	CLD	18:08:44	Zurich Delivery, Hotel Bravo Lima Tango Charly good evening
CLD	LTC	18:08:48	Hotel Bravo Lima Tango Charly, Zurich Delivery, good evening, go ahead
LTC	CLD	18:08:52	Hotel Tango Charly, passing GAC one, information Quebec received, and request start up clearance
CLD	LTC	18:08:59	Hotel Tango Charly, runway 28 to Geneva, ROTOS three yankee departure, squawk 3071
LTC	CLD	18:09:08	Cleared to Geneva, ROTOS three departure, and 3071, confirm the squawk, Hotel Tango Charly
CLD	LTC	18:09:15	Hotel Tango Charly, 3071 is correct, and ROTOS three yankee departure
LTC	CLD	18:09:20	ROTOS three yankee departure, Hotel Tango Charly
CLD	LTC	18:09:24	Hotel Tango Charly, for start up stand by on APRON, 121 decimal 75, good bye
LTC	CLD	18:09:28	12175, Hotel Tango Charly
APR	LTC	18:10:00	Hotel Bravo Lima Tango Charly, Apron, start-up ist approved
LTC	APR	18:10:04	Hotel Tango Charly start-up approved, thank you very much
			-- other stations --
LTC	APR	18:13:50	Hotel Tango Charly request taxi
			-- other stations --
APR	LTC	18:14:10	And Hotel Tango Charly confirm ready to taxi
LTC	APR		Affirm, Hotel Tango Charly
APR	LTC		Hotel Tango Charly, taxi to the holding point runway two eight
LTC	APR	18:14:20	Holding point runway two eight, Hotel Tango Charly
			-- other stations --
APR	LTC	18:15:00	Hotel Tango Charly, when ready to Tower one one eight one

From	To	Time (UTC)	Communication
LTC	APR	18:15:02	One one eight one, Hotel Tango Charly, bye bye
LTC	TWR	18:17:30	Tower, Hotel Bravo Lima Tango Charly, ...runway 28, ready for departure
TWR	LTC	18:17:33	Hotel Tango Charly, Grüezi, hold position, I call you back
LTC	TWR	18:17:37	Hotel Tango Charly
TWR	LTC	18:19:51	Hotel Tango Charly, taxi forward, but hold short of runway 28
LTC	TWR	18:19:57	Hold short of runway 28, Hotel Tango Charly
TWR	LTC	18:20:22	Hotel Tango Charlie, line up runway two eight
LTC	TWR	18:20:26	Lining up two eight, Hotel Tango Charlie
			4 communications between TWR and other aircraft
TWR	LTC	18:20:58	Hotel Tango Charlie, wind two three zero degrees, three knots, cleared take off two eight
LTC	TWR	18:21:03	Cleared take off two eight, Hotel Tango Charlie
			14 communications between TWR and other aircraft
TWR	LTC	18:22:08	Tango Charlie, normal operations?
LTC	TWR	18:22:12	(Ne)gative, Hotel Tango Charlie
TWR	LTC	18:22:13	Say again
TWR	LTC	18:22:19	Hotel Tango Charlie?
LTC	TWR	18:22:21	Mayday, mayday, mayday, Hotel Tango Charlie

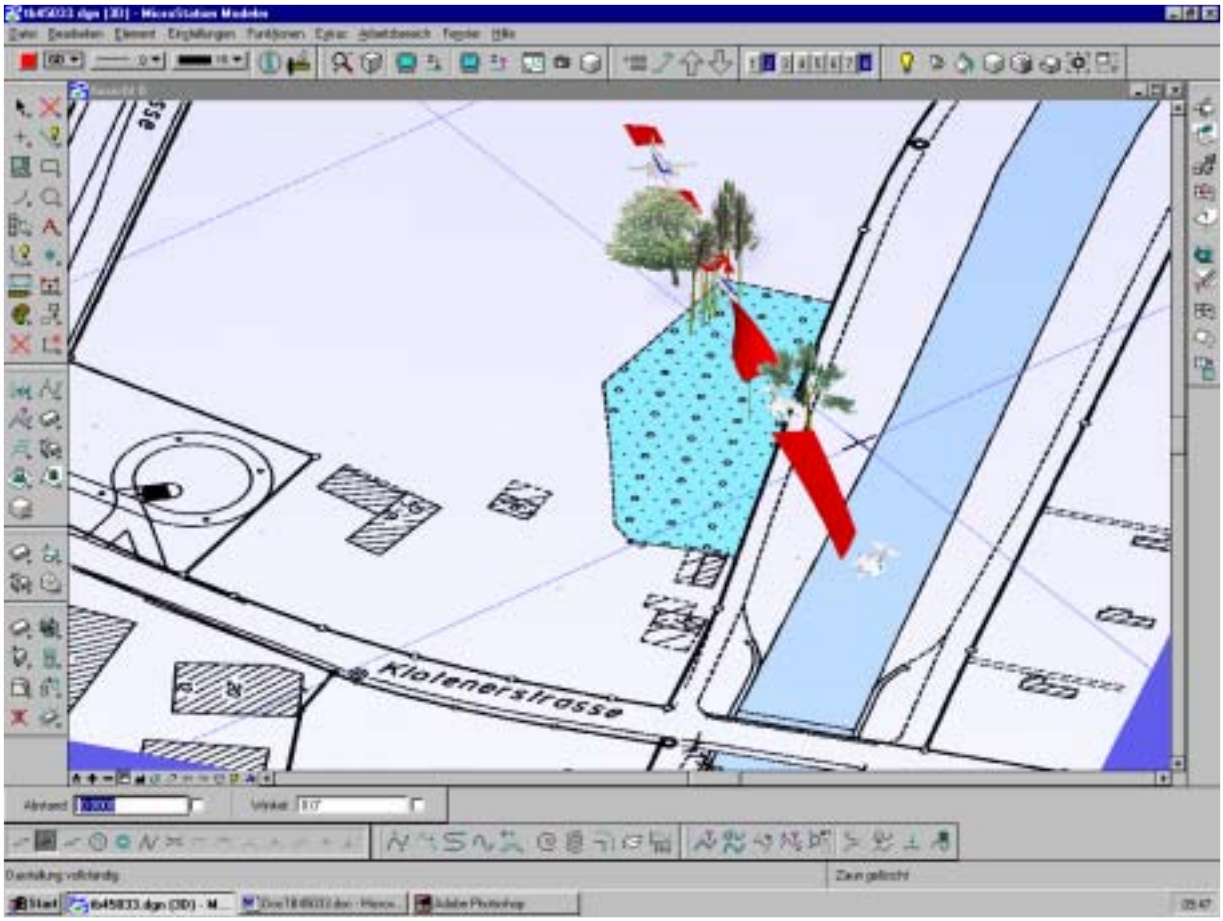
Appendix 2

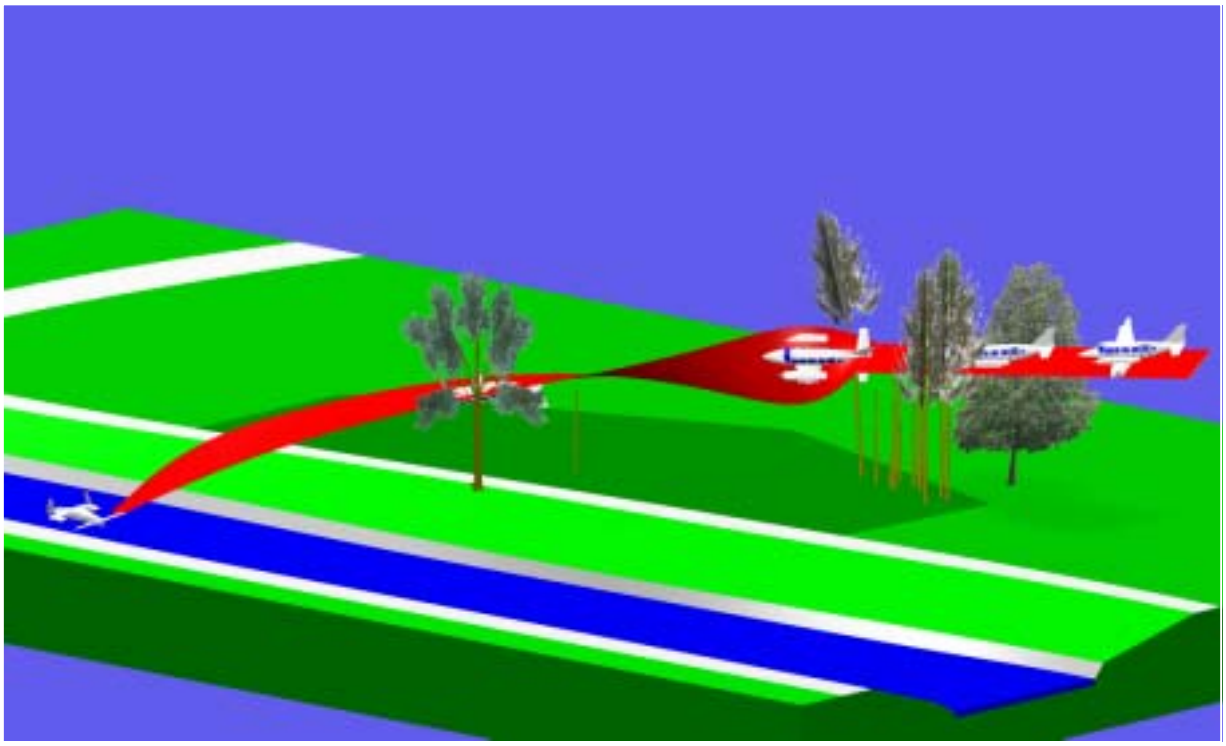
Fuel grade rating placards forward of the tank openings of the main inboard cells of HB-LTC.



Appendix 3

Reconstruction of the last flight phase of HB-LTC.





Appendix 4

Tanker vehicle FL 7 for JET A-1 kerosene.

Appendix 5

Delivery nozzle of tanker vehicle FL 7 (bottom) in comparison with the modified delivery nozzle obtained from the refuelling company with enlarged outer diameter (top).

The delivery nozzle with enlarged outer diameter cannot be inserted into the tank openings of HB-LTC as these were modified to smaller diameters using metal plates.