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Report RO 2001:04e

Bus fire following traffic accident at Fjärdhundra on national route 70, C county, Sweden, 21 November 1998

Case No. O-10/98

The Swedish Board of Accident Investigation (SHK) investigates accidents and incidents from the point of view of safety. The purpose of the investigations is to be able to avoid similar events in the future. SHK's investigations do not, however, seek to ascribe blame or responsibility.

The Report is also available at our website: www.havkom.se

English translation: Tim Crosfield

Statens haverikommission (SHK) Board of Accident Investigation

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2001-12-14 O-10/98

Swedish National Road Administration

781 87 BORLÄNGE

Report RO 2001:04e

The Board of Accident Investigation has investigated a bus fire that occurred following a traffic accident on 21 November 1998 at Fjärdhundra, on national route 70, C county.

In accordance with section 14 of the Ordinance (1990:717) on the Investigation of Accidents the Board herewith submits a report on its investigation.

The Board would be glad to receive, by 30 June 2002, notification on how the recommendations included in the Report are being followed up.

Olle Lundström Jan Mansfeld

Henrik Elinder

Identical text to the Swedish Rescue Services Agency

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1 **Simulated driving cases** (12 diagrams)

2 **Report FFA TN 2000-05**.Experimental investigation of sensitivity to side winds in a model of a double-decker bus in the FFA wind tunnel LT1.
Spreadsheet (diskette).

Appendix 2 may be ordered from the Board of Accident Investigation.

Report RO 2001:04

O-10/98
Report completed 14 December 2001

Bus: registration, type	NUR 172, double-decker tourist bus
Maker, year of manufacture	Chassis: Scania K112 TL Body: Jonckheere Jubilee P99/1988
Latest inspection	1997-11-06
Kerb weight, total weight/kg	16720/22500
Owner/operator	Västanhede Trafik AB
Time of accident	1998-11-21 approx. 18.35h in darkness *Note*: All times refer to Swedish standard time = UTC + 1 hour
Place	National route 70, approx. 1.5 km south of Fjärdhundra exit, C county
Type of journey	Regular traffic
Weather	At Simtuna meteorological station 18.30h; Air temperature +0.6 °C, dew point –0,4 °C, road surface temperature –0.6 °C, average wind speed 7–10 m/s, gusting approx 15 m/s with sleet
Numbers on board: crew	Driver and one assistant
passengers	Approx. 60
Personal injuries	42 injured, of whom at least 7 seriously
Damage to bus	Write-off
Other damage	None
Driver:	
Age, licence	44 yrs, ABE C DE
Experience as driver	4 yrs

The Board of Accident Investigation (SHK) was informed in the evening of 21 November 1998 that an accident involving a bus with registration number NUR 172 had occurred on national route 70 approx 1.5 km south of the Fjärdhundra exit, C county, on that day.

The accident was investigated by SHK represented by Olle Lundström, Chairman, Jan Mansfeld, Chief Investigator, Fire and Rescue Services and Henrik Elinder, Chief Technical Investigator.

SHK was assisted by Hans Carlbom as technical fire expert, Henry Lorin as medical expert and Ronny Widman as vehicle expert.

The investigation was followed by the Swedish Rescue Services Agency represented by Klas Helge.

1 FACTUAL INFORMATION

1.1 History of the journey

In 1998 Säffle Reseservice AB ran regular timetabled traffic between Dalarna and Stockholm at weekends. On Saturday 21 November at 17.30h an express bus with registration number NUR 172 left the Stockholm Central Station bus terminal for Falun. The bus was a double-decker and, as well as the driver and his assistant, had about 60 passengers on board. Most of them sat on the upper deck. The bus belonged to Västanhede Trafik Aktiebolag which maintained regular traffic, with its own staff, on contract to AB Säffle Reseservice.

At around 18.30h the bus was on national route 70 travelling northwest a few kilometres south of the Fjärdhundra exit. The speed was about 90 km/h. It was snowing heavily and the bus encountered a strong and gusty side wind from the left. The driver has stated that the bus suddenly started to skid to the right. He steered to the left to correct this but without effect. He felt as if the bus was being pushed out towards the right-hand side of the road. The wind felt constant. Finally the bus skidded down over the edge of the right-hand ditch. Since the bus was still on its wheels the driver thought he could allow it to continue out on to the field at the other side of the ditch. The bus continued about 60 metres in the ditch before colliding violently with a culvert under a fairly small approach road to a farm. The bus then fell on to its right-hand side, blocking all the doors. In the collision both the upper and the lower windscreen were pressed out. The driver was thrown out and landed in the field.

Another bus, bus 2 was driving behind the accident bus. The driver of bus 2 saw how, in a slight left-hand curve, it was moving further and further out towards the right-hand side of the road. He thought of flashing his headlights to warn the driver, but before he was able to do this the bus left the road in an enormous cloud of snow. He had not noticed any tendency to a skid. When the accident occurred he immediately started braking. The road surface was very slippery but he brought his bus to a standstill about 50 metres beyond where the accident bus was lying. He realised that help was needed and asked his passengers whether there were any on board who worked in the care services. Ten persons said they did and together with them he made his way to the scene of the accident. When they arrived the bus engine was still running at an increasing speed but it stopped after some minutes. He telephoned emergency number 112 and reported the accident, and those assisting him started to help the passengers out through the broken windscreens.

The passengers quickly realised that all the doors were blocked. Those who had been sitting furthest back in the bus had not realised that the windscreens had come out. Some of these passengers tried with a glass-breaking hammer to break a pane on the left-hand side of the bus, which now formed the bus' roof. The internal height was thus equivalent to the breadth of the bus, i.e. about 2.5 metres. The bus had no skylights nor was there a rear window.

The glass-breaking hammer was fixed with a wire at the right hand side of the bus. However, this wire was too short to allow development of enough force to break the window.

Suddenly one of the passengers discovered burning at the back of the bus and that the flames were licking along its side. With shouts, all those in the bus were made aware of the danger.

The driver of bus 2 saw what was happening and realised that rapid help was necessary since the fire would soon be able to enter the passenger compartment. He ran to his own bus and fetched the fire extinguisher. He found that the engine compartment was on fire and the hatch was ajar. He inserted the fire extinguisher hose there and sprayed and the fire went out. However shortly thereafter it started again. He was then able to borrow a fire extinguisher from a lorry, but its capacity was too small so the fire was only dampened somewhat. The only thing he could do was to help with the passengers. Suddenly a sharp bang was heard and the whole passenger compartment appeared to catch fire. He and the other helpers struggled to get everyone out. They discovered a woman who had got stuck in a broken window behind the driver's seat, but finally they got her out also. Her clothes were on fire when she came out, but this fire was put out with snow.

The municipal rescue services arrived on the scene at 18.50 h, by which time the bus was all in flames. The rescue operation is reported in section 1.4.

First the casualties were assembled in front of the burning bus at the side of the road and other passengers on the road behind bus number 2. Many of the passengers were lightly dressed. All those affected, however, got seats while waiting for further measures in bus 2 and in other vehicles that had stopped at the site.

1.2 Personal injuries

1.2.1 Persons receiving care

The medical services hold data regarding 60 passengers and the driver and his assistant.

Age and sex distribution

Birth-year group	*numbers of men*	*numbers of women*	*total*
1925–29	0	1	1
1930–34	1	0	1
1935–39	2	4	6
1940–44	3	2	5
1945–49	0	0	2
1950–54	2	6	8
1955–59	0	2	2
1960–64	3	6	9
1965–69	1	8	9
1970–74	2	4	6
1975–79	0	1	1
1980–84	1	5	6
1985–89	2	2	4
1990–94	2	0	2
1995–98	0	0	0
	19	43	62

1.2.2 Distribution of severity of injuries

Using the particulars the Board has been able to obtain, an attempt has been made to asses the degree of severity of the bodily injuries incurred by those who were travelling in the bus. In the table below and on the sketch in section 1.2.4 signifies:

0 = no injury or only insignificant scratches
1 = light injuries but requiring physician's assessment and medical measure or a period of observation
2 = severe injuries, life-threatening or with risk of invalidity
1–2 = doubt as to whether these people should be placed in group 1 or group 2 on the basis of the particulars received
? = no information on possible injury.

Distribution of injuries

Injury level	0	1	1–2	2	?	Deaths	Total
Numbers	14	32	3	7	8	0	62

1.2.3 Medical injury panorama

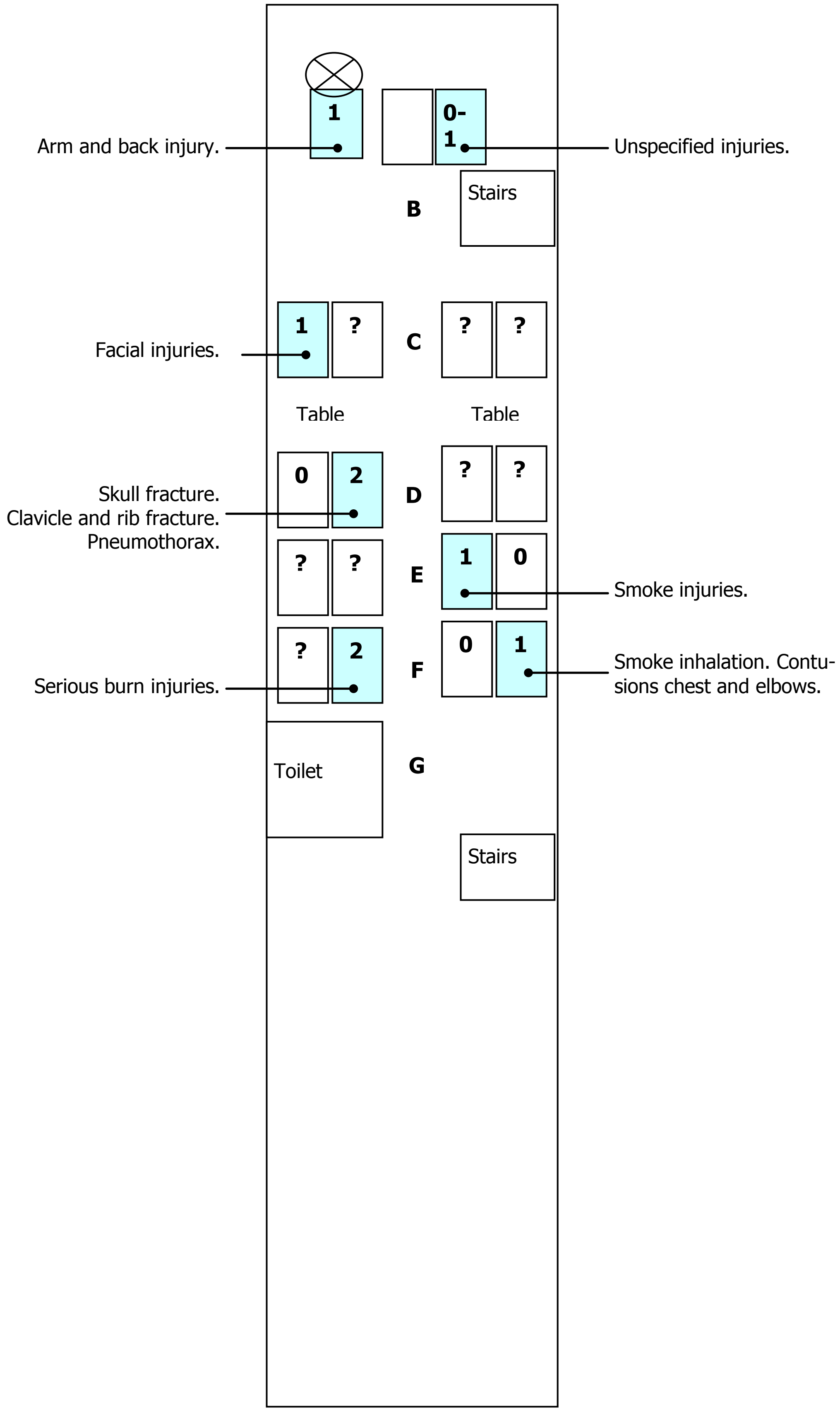
With the violent impact the passengers were thrown forwards in the direction of the bus' travel. The driver and the passengers furthest forward were thrown against the windscreens, which were pressed out from their frames and landed on the field.

The accident produced a broad sample of different types of bodily injury. Dominant were contusion injuries with bruises and pain in various parts of the body. About ten of the passengers incurred fractures. In many cases these were rib fractures, in some combined with pneumothorax (injury to the pleura). There was also a case of fracture of the skull base, followed by paralysis of facial nerves. Back pain, including cervical was common. Three of the cases incurred fractures of cervical vertebrae, in one with serious paralysis below the fracture. There were also cuts on the face and/or hands.

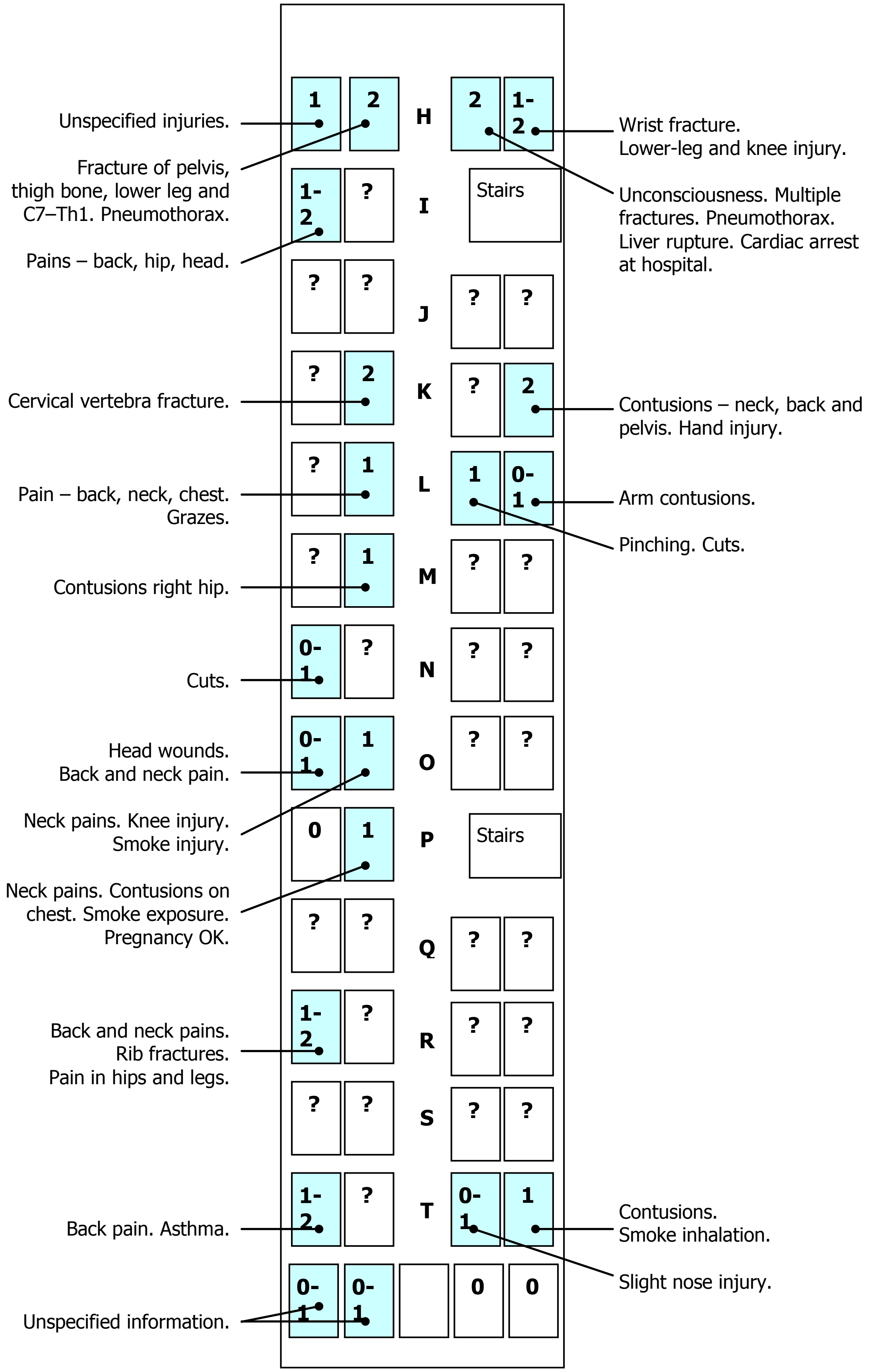
Fire did not break out in the rear parts of the bus until after a few minutes, for which reason many of the passengers had been able to make their way out and were not exposed to the smoke. But some cases were affected by smoke during evacuation of the bus and had trouble persisting for some days. There was however, no carbon monoxide poisoning with serious effects on consciousness. One woman who was unable to make her way out of the bus, but was helped out, incurred serious thermal burns to the skin of the left hand, arm and leg and buttocks and left flank. One passenger who had multiple fractures, ruptured liver, pneumothoracic injury and extensive trunk bleeding did however suffer cardiac arrest at Uppsala University Hospital (UAS), but was resuscitated and survived.

For placing in the bus, see below.

Bus, lower deck



Bus, upper deck



1.3 The Fire

Fire broke out in the engine compartment shortly after the bus left the road, and burnt its way through the engine compartment hatch. Flames flared up into the open air. The fire spread into the passenger compartment from outside and into the bus where fittings ignited. The flames destroyed the larger part of the fittings on the upper deck of the bus.

1.4 Rescue operations

1.4.1 *Evacuation and life saving*

Introduction

On 17 February 1999 SHK sent a questionnaire to all the passengers for whom names and addresses were available. A summary made on the basis of the answers from the 25 passengers who sent the information requested shows that many of the passengers needed help to get out of the bus. In certain cases others in the bus were able to help but many needed help from outside. The questionnaire answers form part of the material used in this section, as do the reports and compilations received from the rescue services and hospitals. SHK was also represented at the enquiry arranged by the Uppsala County Administration Board in Enköping on 17 December 1998. On this occasion the various representatives of the community services concerned in the accident reported on their different contributions; including the National Road Administration, the municipal fire and rescue services, ambulance services, medical care, the police, the psychological-psychiatric disaster management groups (PKL) and the Swedish Church. After this meeting the County Administration Board evaluated the community's operations in connection with the accident.

The evacuation phase and the voluntary assistance

Some younger men travelling in bus 2 made their way into the overturned bus and helped lift and carry out casualties. They continued their work even after the bus had started to burn. The last person they helped from the bus was the woman who had got stuck in a window. Her clothes were on fire. She was freed and the burning clothes extinguished with snow. According to information received practically all were out of the bus when the rescue services arrived.

There was not the full number of glass-breaking hammers in the bus. According to representatives of the bus industry thefts of these hammers sometimes occur. To hinder this, the hammers were fixed to the bus with wires. When the bus was lying on its right-hand side, as mentioned, the distance between available hammers on the right-hand side of the bus and the windows on the opposite side was so large that the wire prevented exertion of full force in the blows. In one or two cases however it was possible to make a fairly small hole in one pane. Using hands, bits of cut glass were broken loose so that the hole became large enough to force oneself through.

Those sitting on the left-hand side of the bus left their seats and tumbled down to the right. Many injured themselves in the fall since they struck fittings in the bus. Several of these lost consciousness. Despite this, all got out or were helped out of the bus before the smoke and the flames rendered it impossible to remain there.

The majority of the passengers made their way out through the large front panes. On the lower deck a pane just behind the driver's seat also served some people as an exit.

This bus type had no skylight which in the situation that arose meant that only the windscreen panes and the windows on the left-hand side could be used for evacuation and life-saving. While there was a door on the lower deck on the left-hand side of the bus, this was blocked by a table and two double seats turned towards one another.

The alarm phase

At the emergency centre (SOS Alarm) in C county on the evening of the accident two emergency operators were on duty plus what is termed back-up command. At 18.35h a message was received via a mobile telephone regarding a bus accident on national route 70 between Gästre and Fjärdhundra. A red alert was issued. The Centre was then reinforced by two emergency operators and the chief ambulance physician at Uppsala University Hospital (UAS), as well as the Uppsala county stand-by chief of ambulance care.

The following fire and rescue stations were alerted:
18.37h station 200, Enköping
18.38h station 230, Veckholm
18.39h station 170, Knivsta
18.41h station 220, Örsundsbro (stand-by alert, red alert issued 18.45h)
18.42h station 250, Fjärdhundra (order to stand-by, one vehicle called out 18.49h).

The rescue services plan for a municipality specifies action times for the different rescue forces. The action time is the sum of the times for turn-out, driving and attack. By turn-out time is meant the time from the alert being received at the station until the rescue force leaves. Driving time is of course the time for the move from the station to the scene of the accident. Attack time is the time taken from when the force has arrived to commencement of the first active operation.

For a full-time rescue force such as that in Enköping a normal turn-out time is 60–90 seconds. For a part-time force, such as the other rescue forces in this case where the firemen as a rule are in their homes or at their places of work, the turn-out time cannot as a rule be shorter than about five minutes.

Since operation forces are called out via the SOS Alarm centre in Uppsala, written emergency plans for different types of operation are held there. In a large accident in Enköping municipality the first to be alerted is the main station, which has the shortest turn-out time and the greatest material resources. In the case of fire, the closest part-time force is also normally alerted.

When the SOS Alarm services centre was telephoned by the driver of bus 2, no fire had been observed. According to the emergency plan an alert should be issued for the event “bus accident” in the Fjärdhundra fire station area and then supplemented with “large injury site in Enköping municipality”, and this was done. When it subsequently became clear that fire had broken out, a certain lack of clarity in the emergency plan led to the Fjärdhundra station – which was closest to the site of the accident – moving far down in the chain of alert.

For the present accident, as mentioned, the rescue force in Veckholm was also alerted. The job of this force is to bring to a large accident with many casualties a disaster vehicle with special equipment including a medical care tent. Such a vehicle was also available at the Knivsta station. The tents were not erected, however, since the Incident Commander judged that the casualties already had access to warm places in bus 2 and in private cars.

According to information from both the Enköping rescue service and the SOS Alarm centre in Uppsala the emergency plans have now been altered so that the closest rescue force must always be alerted first, irrespective of the type of operation required. To ensure that this is done, the staff members at the various stations who acknowledge the alert from the SOS Alarm centre must ask the emergency operator whether the nearest fire station has been alerted.

It has been impossible to establish from the alert log when the Fjärdhundra force was ready to depart. Nor is there any information on when this operation force arrived at the scene of the accident.

At 18.43h the police reported that four cars had been ordered to the scene of the accident.

The rescue operation

Between three and five minutes after the first alert message to the municipal rescue services in Enköping, information was received that the bus was on fire. For this reason, while on the way to the accident, the Incident Commander requested reinforcements from his own municipality with both full-time staff and part-time staff, but also from Uppsala. Over and above the ambulance that accompanied the first call-out, more were alerted. To be sure of having as many medical resources at the scene of the accident as possible, the ambulance crews were divided so that the ambulances were driven to and from the scene of the accident by a fireman.

According to the first information received by the rescue services when they arrived, there were still people inside the bus. It was however impossible to get into the bus because of the smoke and heat. Under these circumstances the rescue services could only aim to search the bus as soon as this was possible.

When the rescue staff arrived they helped look after the woman who had got stuck in a window. She was the first casualty looked after and was taken by ambulance to Enköping hospital. According to rescue services information, this took place within five minutes of their arrival. The most seriously injured people were then removed by ambulance while the others continued in buses requisitioned by the rescue services.

The municipal rescue services helped a total of 47 people. The exact number of passengers in the bus has been impossible to establish. According to information from the hospitals, 62 people were treated or checked. There is information to show, however, that in some cases passengers may have been given lifts from the scene of the accident in private cars.

1.4.2 Fire-fighting

The fire was attacked with two powder extinguishers and two water hoses. After about ten minutes it was put out.

The rescue services estimated that it took about 8 m^3 of water to put the fire out. While it was being extinguished, firemen searched the bus to make sure that nobody remained in it.

1.5 Ambulance and medical care operations

1.5.1 Introduction

It is the task of SHK to scrutinize the rescue operations conducted by the public rescue services at the scene of an accident. The subsequent medical care measures are not included in SHK´s prescribed terms of reference. In this case, however, SHK has felt it important to report briefly on this part of the care to illustrate what resources may be required following an accident of this size.

1.5.2 General

The ambulances in Uppsala county belonged to the county council/medical care but were stationed at the fire services stations. There were 14 ambulances with crews. Ambulance medical orderlies had undergone a 20-week course of basic training and annual one-week continuation training in ambulance and acute medical care. The acute ambulance crews included nurses.

The purely medical responsibility for ambulance operations in the county belonged to UAS. The chief ambulance physician at the hospital was responsible for the equipment of the ambulances and the competence of their staffs in normal circumstances.

In red alert at a fire station an ambulance accompanied the call-out. In addition, when there were more than six casualties at the scene of an accident, the disaster vehicles mentioned earlier were automatically sent.

1.5.3 Alert

The following medical resources were alerted:

Starting at 18.39h the two twenty-four-hour ambulances belonging to the Enköping station were sent on alert together with an ambulance manned with staff who happened to be at the station at the time. Further staff were called in, whereupon a further ambulance was sent to the scene of the accident somewhat later.

Since assistance had been requested from Stockholm county at 18.49h according to logged information five ambulances, one acute vehicle and one helicopter were sent at 19.06h.

Further, ambulances were requisitioned from Västerås and Sala, one medical helicopter with doctor and nurse from Uppsala and one Defence Forces helicopter from Berga with a medical team from Huddinge University Hospital. To these should be added the earlier-mentioned disaster vehicles from Knivsta and Veckholm.

At around 18.40h emergency reception at Enköping Hospital received information about the accident. The primary duty surgeon notified his back-up, who was in his home, whereupon disaster alert was declared at the hospital.

A physician at UAS, who had heard a request from the SOS Alarm centre for staff to the medical care helicopter, informed the hospital emergency department. From there the SOS Alarm centre was contacted and gave details of the accident. The time was then around 18.55h.

The chief ambulance physician, who was also preparedness chief of the ambulance services, received information from the SOS Alarm centre that at least 36 people had been injured. In consultation with the duty surgeon he then decided to send a medical team to the scene of the accident as well as the medical helicopter.

The physician and the nurse who were to go with the Uppsala medical helicopter were fetched from UAS at 18.55h. However, the weather was such that the helicopter would have been unable to reach the scene of the accident. Instead the doctor and the nurse were transported there by taxi.

The medical team from Huddinge University Hospital could not be transported to the accident site by helicopter, either, because of the heavy weather. It became necessary to land in Bålsta and the medical team then covered the remaining distance by car.

Enköping hospital sent two medical teams each consisting of a doctor, a nurse and an assistance nurse. The first team was ready to leave at 19.15h and this was reported to the SOS Alarm centre. They were informed that a police car would pick them up. But no police car arrived. The police station in Enköping was shut since it was Saturday evening. At 19.30h the second team was also ready to be picked up. The first ambulance to arrive with an injured passenger returned to the scene of the accident at 19.35h with both medical care groups.

1.5.4 Medical work at the scene of the accident. SOS Alarm centre

Those responsible for the first medical aid at the scene of the accident were uninjured passengers in the crashed bus and people who had been travelling in bus 2 and in private cars. Rescue vehicles and ambulances arrived successively. The first ambulance to arrive became command ambulance. When the rescue services arrived the most seriously injured people lay in front of the bus in the slush on the muddy field. Two firemen were detailed to extinguish the fire in the bus while the others, together with ambulance staff, started helping those in need. One of the medical orderlies from the command ambulance attempted to assess the injuries and make priorities for transport to hospital. No specific treatment was given at the scene of the accident except oxygen to two seriously injured people. Neck-supporting collars were used in several cases during transport.

When the physician and nurse intended to accompany the Uppsala county medical helicopter arrived on the scene, a very seriously injured woman was ready for transport on a vacuum mattress to Enköping hospital. The physician ordered that the patient be unloaded and that the woman who had got stuck in the window and sustained serious burn injuries should be taken instead. A fireman and an ambulance orderly drove her to Enköping. The other woman was also later taken by ambulance to Enköping. The physician later accompanied a seriously injured person to Enköping hospital and then continued with a patient with back injuries to UAS.

None of the physicians in the groups sent from Enköping were trained as command physicians. One was a district medical officer and the other a general practitioner. There was a physician with command physician's training at the hospital, but he was judged to be more needed there.

Apart from the physician and the nurse who should have accompanied the ambulance helicopter from Uppsala, the teams from Enköping were the first on the scene. The majority of serious casualties had then already been transported away. On arrival at the scene of the accident, one of the physicians in the two teams contacted the command ambulance staff and the Incident Commander. However, he was not to exercise any real medical command.

The medical team from UAS consisted of an anaesthesiologist and two nurses. They were transported by ambulance to the scene of the accident. The physician from Uppsala who had arrived earlier reported that no casualties remained so the team returned.

The operations at the SOS Alarm centre were reinforced, as mentioned above, with two emergency operators and “stand-by chief of ambulance care”. The latter took no part in the transport of the first casualties since these had already been sent to hospital when he arrived at the SOS Alarm centre. The command ambulance staff were clear about how the casualties should be distributed. However, the physician who arrived by taxi from UAS had altered the priorities regarding the person to be sent away first. The physician at the emergency services centre then maintained contact with the command ambulance staff and most of the operation was in consultation between them.

The basic concept was to direct the first ambulances to the nearest hospital so as to be able to get them back quickly. It could be unsuitable to send the ambulances early to UAS since the distance was great and road conditions poor. Particularly Enköping, but also Västerås, were nearer. The intention was not that the casualties should be admitted for qualified measures and investigations in Enköping. Following necessary acute medical treatment the patients were to be transported further in different ambulances as soon as ambulance availability became sufficient and the casualties could tolerate longer journeys.

1.5.5 Activity at Enköping Hospital

Enköping hospital included a surgical centre. From this on the evening in question, three general surgeons, two orthopaedic surgeons, two anaesthesiologists and two radiologists assisted. All were senior in their fields. One of the orthopaedic surgeons, who was primary duty physician, was at the emergency department the whole time.

For reasons of economy and rationalization there were no duty operational staff on Saturdays, Sundays and holidays. Nor should there be extensive care to any great extent, for which reason there was no elective surgery involving sizeable interventions on Fridays. However, emergency preparedness was maintained at the hospital on all days.

The back-up duty surgeon arrived at the hospital at around 19.05h. No patients had then arrived. Elements of a disaster office were established. Other necessary staff were called in. They were divided into teams each consisting of a physician, a nurse and an assistant nurse tasked to follow the patient allocated to them during the evening. There were plenty of beds. The intensive care department (IVA) was completely emptied.

At around 19.15h information arrived from the SOS Alarm centre that the hospital was to accept 4–5 seriously injured people and about 15 light casualties. Preparations were made to channel the lightly injured further to IVA where two physicians from the medical clinic were to take care of them.

Around 19.30h the first patient arrived at the hospital, a woman with 40% burn injuries. She was treated for shock, given oxygen and pain relief and at around 20.00h was sent on to UAS.

The next seriously injured patient was a woman with among other things, chest injuries and severe arm fractures. She was x-rayed, with an anaesthetist in attendance.

Of the 12 patients admitted to Enköping hospital four were seriously injured of whom the condition in two cases was judged by the physicians to be critical. These four patients were, after measures, sent to UAS. One patient with neck injuries was referred to Falun and a man with leg and arm fractures was taken to Västerås. Six casualties spent the night at the IVA.

At 22.35h disaster status at the hospital was ended.

Staff have stated that shortcomings were experienced in a number of external respects. Questions were received as to where casualties had been sent and in many cases information was lacking. Nor was it known where worried relatives who called should be referred. It was not known where and by whom in the police these questions were being handled. It was considered that there was a need for co-ordination of such and similar questions through simple routines known to the parties involved.

1.5.6 Activity at Uppsala University Hospital (UAS)

The first casualty case arrived at the hospital around 20.45h. The next came about half an hour later. More casualties arrived successively. The seriously injured woman with among other things pleural injury arrived last after first having been cared for at Enköping hospital. Her condition was critical and it was necessary to apply Bülow drainage immediately.

The casualties were registered, examined and “sorted” at the entrance to the casualty department by a surgeon. Police assisted with registration. The seriously injured were cared for at the casualty department while the slight casualties were taken to the surgical department. There, 22 patients were examined and treated. Eleven of these remained overnight at the admissions department, in most cases because it was difficult to send them home at that time.

Thirteen casualties were admitted to hospital, of whom four to the recovery ward, three to IVA, one to the surgical department, one to neurosurgery, one to plastic surgery and two (mother and child) to the children’s clinic. In addition, one casualty was transferred from Västerås to the orthopaedic department during the night.

In a bus that arrived at UAS from the scene of the accident there were uninjured and slightly injured people, but also passengers from bus 2. The uninjured passed through the casualty department up to the psycho-social centre, where police and PKL staff registered them and took care of them. Many from bus number 2 also felt unwell and were looked after.

The hospital support and relatives centre looked after about 50 people during the night. Many then continued by bus at midnight. Sixteen uninjured people spent the night at the hospital. Travel home was arranged for them the following morning.

1.5.7 Other hospitals

Three casualties were sent direct from the scene of the accident to Karolinska Hospital in Stockholm. Of these, one was sent home the same evening, one was admitted for cervical vertebral injury and one was kept overnight for observation.

Two casualties were sent direct to S:t Gorans Hospital in Stockholm and admitted for observation of abdominal and back injuries, respectively.

Two casualties with smoke and back injuries respectively were sent direct to the hospital in Västerås and were admitted there. A third patient, who was first examined in Enköping, also came to Västerås. However, he was transferred during the night to UAS since his wife was being cared for there.

A woman with neck injuries was transferred during the night from Enköping Hospital to the hospital in Falun.

1.6 Damage to the bus

Total write-off.

1.7 Other damage

There was limited environmental damage in the form of fuel and oil release. The major part of the escaping fuel and lubricating oil was burned up.

1.8 Bus staff

1.8.1 The driver

The driver was 44 years old at the time and held a valid ABE C DE licence. The bus licence was issued on 2.12.1994. He also had other work during the week. He was familiar with the route.

1.8.2 The assistant

A young girl (15 years old) arranged coffee, but according to information received had no other special duties on board during the journey. However, many passengers had seen her as a representative of the operator and felt they could make certain demands upon her at the time of the accident. Some have pointed that her possible training in how to behave in the case of an accident appeared in this case to be inadequate.

1.9 The vehicle

Manufacturer:	Chassis: Scania K 112 TL Body: Jonckheere Jubilee P99
Serial number:	Chassis KT6x2B01812621
Year of manufacture:	1988
Registration number:	NUR 172
Kerb weight:	16,720 kg
Total weight:	22,500 kg
Maximum permitted load:	5,780 kg
Maximum number of passengers:	71
Utilization:	Regular and tourist traffic
Engine:	DSC 1101B
Fuel:	Diesel Mk 1
Wheel axles:	One front axle and two rear axles
Steering:	Servo steering

The bus was last inspected with approved result on 6 November 1997 (protocol 0324). The tachograph was checked according to regulations in force on 21 October 1998. The air conditioning plant was also checked and approved.

The bus was, as mentioned, a double-decker, with room for 53 passengers on the upper deck. It was 12.2 metres long, 2.5 metres broad and 4.0 metres tall. In a continuation sheet to the certificate of registration of 10.7.1992 it was stated that “with the baggage compartment fully used as regards weight the number of passengers may not exceed 58”. “Maximum load in luggage compartment 1710 kg”. SHK has been unable to check whether the number of passengers and the current load were within permitted limits since the number of passengers was somewhat uncertain and the luggage compartment was empty of passenger luggage at the time of the investigation.

In the following description of the bus the terms right and left refer to its direction of travel.

The upper deck of the bus was a passenger compartment only, and reached by two flights of stairs. The lower deck, counting from the front, consisted of the driver's seat, a sleeping cabin on the left and the forward stairs on the right, space for passengers, toilet, rear stairs on the right, pantry, luggage compartment, engine compartment and a compartment for the air-conditioning plant. The condenser for the air conditioning plant was placed in a compartment above the engine compartment.

The bus had four doors, of which three were on the right-hand side. The forward and middle of these were for ascending and alighting and the rear one for loading and unloading luggage. The fourth door was, as mentioned above, on the left-hand side of the bus, but was blocked and therefore unusable.

For a reliable impression of the bus’ appearance before the fire SHK had the opportunity to investigate a bus of the same type and version. This bus had registration number NUY 230 and in what follows is termed the twin bus.

Bodywork

As with many other bus types, hatches and part of the outside walls including the rear wall were of fibreglass-reinforced plastic. This material has low resistance to fire.

The interior walls of the bus were surfaced with textile glued directly to the underlying material.

Engine compartment

As mentioned earlier the engine compartment was furthest back in the bus. The engine was a turbocharged diesel from Scania Vabis, a straight-six-cylinder engine with the crankshaft longitudinally in the bus. At high engine loading the turbocharger fan housing develops a temperature of between 600 °C and 700 °C and the manifold between 350 °C and 450 °C. The engine could be stopped electrically using a button on the dashboard, but also from a control panel in the engine compartment.

Combustion air to the engine was drawn in through a grid situated behind the rear axle of the bus on the left-hand side, where the air cleaner was also situated. The air was conducted through a spirally-reinforced tube diagonally through the engine compartment to the engine induction manifold on the right-hand side of the bus.

The engine was water-cooled. The cooling plant was situated in the engine compartment to the far left in the bus. Behind this plant, in the direction of travel, was a large fan to force the air through this. In front of the cooling system, there was a second cooling system, a pressurized air cooler, earlier termed intercooler, the function of which was to cool the intake air to the engine so as to improve efficiency.

From the manifold the exhaust pipe went backwards and then obliquely up to the left across the engine, to emerge finally on the left-hand side of the rear of the bus.

The fuel tank containing approximately 400 litres was situated above the transmission shaft in the rear wheel bogey. The fuel lines were partly of steel and partly of inflammable material. The return fuel line was of inflammable material. The engine was supplied with fuel from an injection pump, directly driven by the camshaft. The pump was cooled by the fuel, so that there was a large flow also in the return line from the cylinders. The fuel line had a water separator with a glass collector. The collector was in the shape of a small glass jar held in place by a steel stirrup. The glass was situated on the right-hand side of the bus between the compressor mentioned below and the engine block.

On the right hand side of the engine compartment was mounted the compressor which was part of the air-conditioning plant. The compressor was mounted on four rubber cushions and connected to the engine with a hinge joint which permitted the compressor to move upwards and downwards. It was driven with double V-belts from the crankshaft. The belt tension was maintained partly through the weight of the compressor itself but there was also an adjusting screw in the vicinity of the collector jar mentioned above.

Near the compressor there was an electrical distribution box which permitted the engine to be started from the outside from this place. To the right of the compressor a helically-reinforced tube supplied the engine with combustion air.

The engine compartment was fireproofed from the luggage compartment with a partition and from the passenger compartments by the air-conditioning plant. The front portion of the engine compartment could be reached, however, from the luggage compartment through a screwed-on hatch.

There was no fire alarm in the engine compartment of this bus type.

Luggage compartment

As well as the door on the right-hand side of the bus the luggage compartment was accessible via three hatches, a large one on the right-hand side and a smaller and a large on the left-hand side.

On the left-hand side of the bus near the engine compartment there was a fairly small compartment containing a heating unit with an oil burner and a water pump which caused the water to circulate to the radiators in the bus.

The luggage compartment was fireproofed from the passenger compartments, the toilet and the pantry with a dense wall.

Toilet

The toilet was situated on the left-hand side of the bus in line with the rear passenger door. The toilet door opened outwards and was hung to the left.

Pantry

The pantry was in the extension of the aisle between the passenger seats and with its right-hand side towards the stairs to the upper deck.

Ventilation plant

The bus was equipped with a ventilation plant that supplied the passenger compartment with treated outside air. The air was drawn in through grids, one on the left-hand side and one on the right-hand side just forward of the rear-wheel bogey. The plant was situated largely above the engine compartment but under the upper-deck floor.

1.10 Weather conditions

The nearest Swedish Meteorological and Hydrological Institute (SMHI) station is five kilometres east-south-east of Sala centre (automatic station). The following particulars were read during the station's observations on 21 November 1998 at 19.00h:

Wind: south-west 7 m/s, no gusting reported.
Visibility: reported as 8 kilometres in mist and overcast weather (but no snow just then).
Temperature: +0.6 °C (rising).

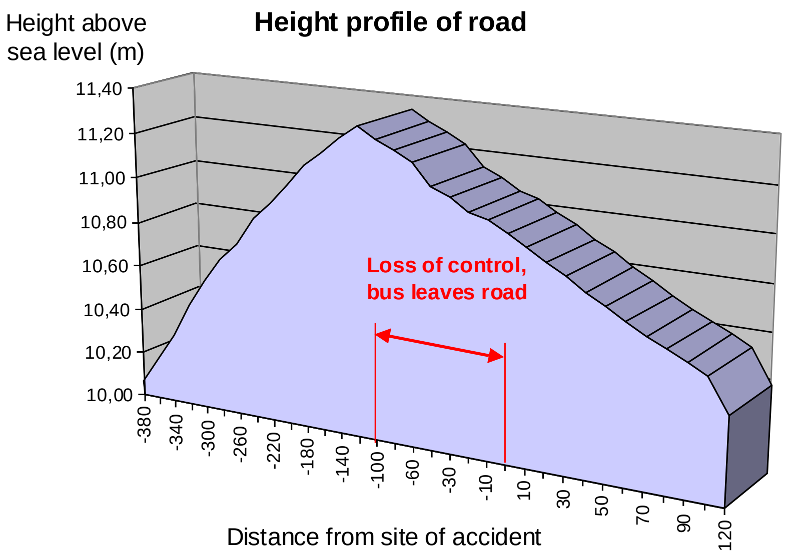
The following comments were made by SMHI. “The station is on level open ground but there is a copse in the direction of the wind at that time only 10–20 metres away and the wind was thus somewhat hindered. In more open country mean wind speed probably 7–10 m/s and gusts around 15 m/s.”
(Underlined by SMHI).

The closest national Road Administration weather station, Simtuna, reported at 18.31h: sleet, road surface temperature –0.6 °C and air temperature +0.1 °C.

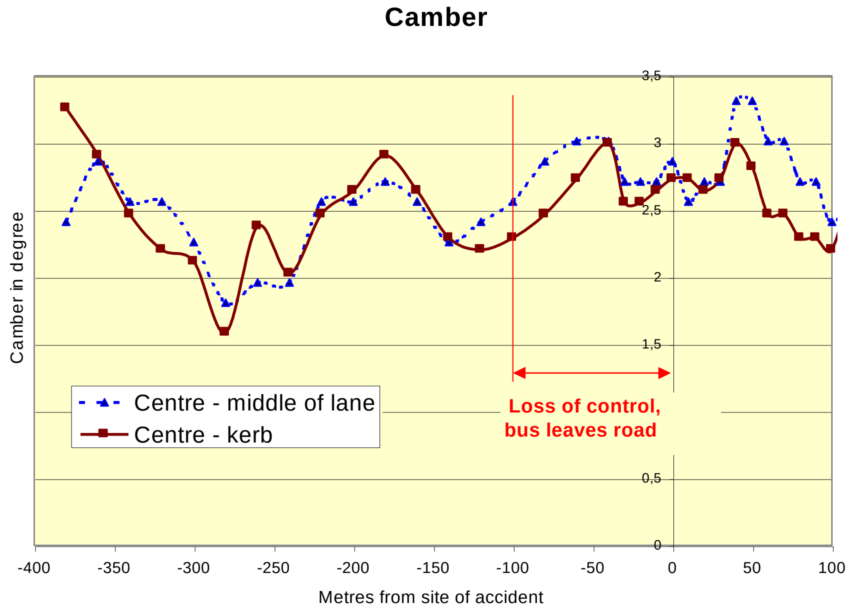
According to many witnesses at the scene of the accident there was heavy and gusty wind at the time of the accident.

1.11 Road data

The height profile of the road at the road section in question is shown in the diagram below.



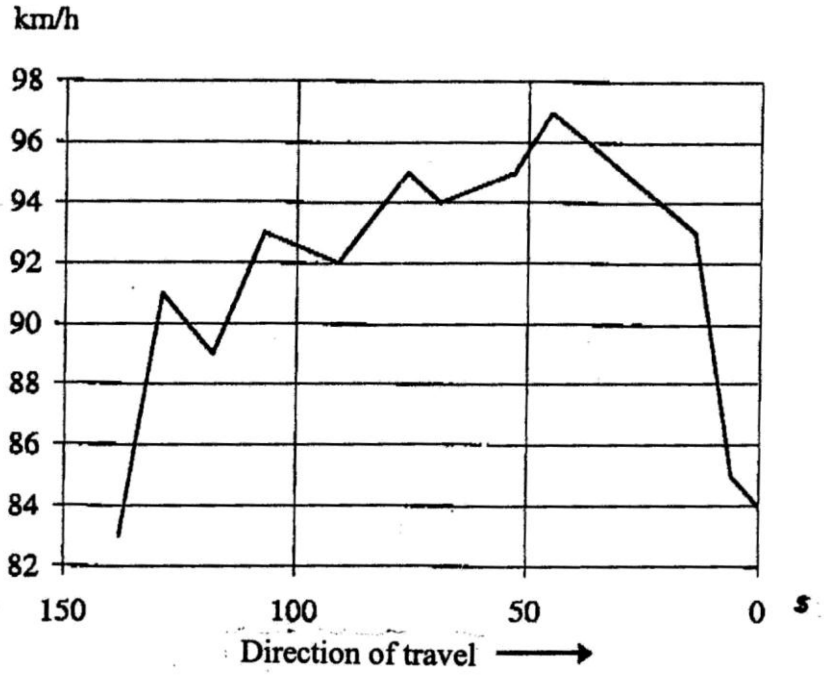
The metalled road surface is 13 metres broad in total. Lane lines are marked on each side 3.8 metres from the centreline. At the spot where the bus left the road there was a grass verge of about 0.8 metres in breadth between the edge of the metalling and the slope. In the diagram below, the camber has been drawn in for the road section before and after the site of the accident.



At the time of the accident the road was covered with an approximately 1–2-cm layer of wet snow.

1.12 Tachograph

At the request of the police authority in Uppsala county, the Swedish Testing and Research Institute (SP) evaluated the tachograph diagram. In the result of the investigation it was noted that the recorded zero line for speed was approximately 0.1 mm too high. Because of this error, the tachograph had recorded approximately 1 km/h too high a speed. The speeds given below have therefore been corrected with reference to this error. The evaluation covers the vehicle's travel 3553 metres before and up to an unnatural recording which probably represents the accident. After this unnatural recording, when the bus probably overturned, the diagram sheet continued to register speeds for approximately 250 seconds.



The lowest recorded speed during the stretch above was 83 km/h but this was maintained by the driver only for a short distance. For large parts of the stretch, speed was over 90 km/h with the highest value 97 km/h for a short period. Speed varied greatly in the range 90–94 km/h.

The most recent report following a check of the tachograph equipment in connection with its installation according to the National Road Administration regulations then in force showed that it met the requirements. The check was performed by Bil & Buss i Dalarna AB, Hedemora, on 21 October 1998. (Report number I/B number 472.)

1.13 Scene of accident and wreck of bus

1.13.1 Scene of accident

The scene of the accident is a few hundred metres north of the side road to Blåsbo. After the right-hand wheels had left the road metalling and the grass verge outside this, the bus slid along in the ditch for some 60 metres to the road shoulder of the side road leading to Övre Gästre. Under the side road there was a culvert. The bus struck the shoulder and the culvert was the solid obstacle that finally stopped it.

The side of the ditch had a slope of about 1:4 and sloped for about 2.6–2.7 metres. Where the bus finally ended up, the slope was 2.8 metres.

1.13.2 Wreckage

The forward section of the bus was pressed in on the right-hand side. Extensive fire damage arose in the engine compartment and in the upper part of the bus. Economically, the bus was considered a total wreck. More detailed report of the damage is given in section 1.17.

1.14 Medical information

Nothing has emerged to indicate that the driver's physical or mental condition was impaired before or during the journey.

1.15 Wind forces on buses

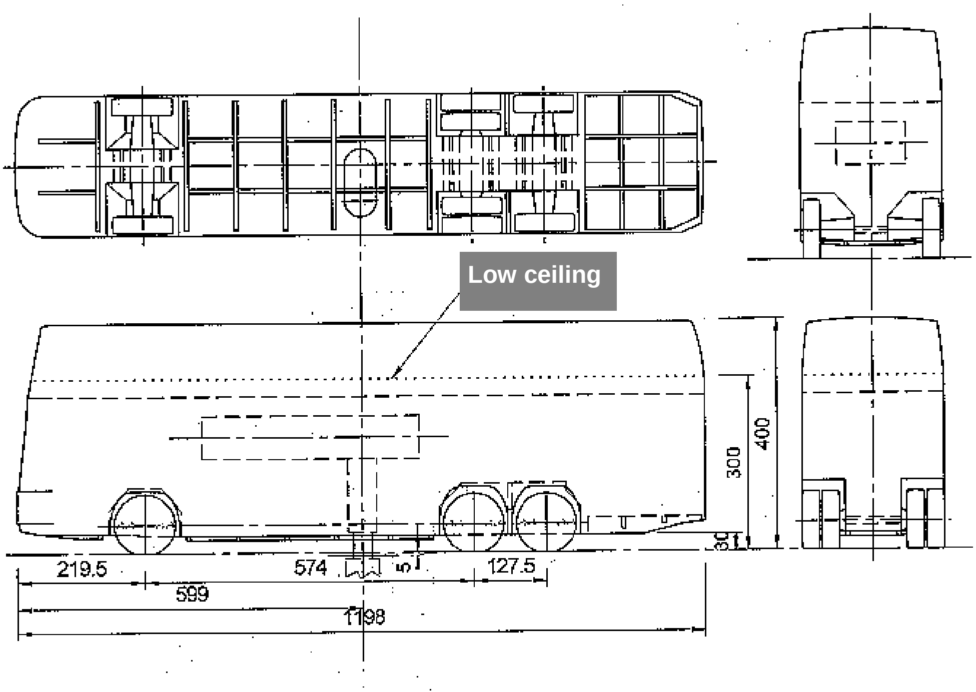
1.15.1 Introduction

In the accident the driver experienced that the bus “was being pressed” out to the right-hand side of the road and that it could not be steered back. At the time road surface was covered with wet snow and there was a strong and gusty wind from the left. It has been asked during the investigation how the driving characteristics in tall, double-decker, long-distance buses of this type are affected by side winds while driving. A literature review shows that it is hard to find information on the characteristics of buses at large diagonal wind angles. The then Aeronautical Research Institute in Stockholm (now part of the Total Defence Research Institute, FOI), therefore, at the request of SHK, conducted an experimental investigation of side-wind sensitivity in a model of the bus in a wind tunnel. By processing measurement data from the model trials the true forces have been calculated. The result of the investigation is presented in FFA Report FFA TN 2000-05. The present sections 1.15.2–1.15.8 summarise the FFA report.

1.15.2 *The model*

For the trial a wooden model of the bus type in question was made on a scale of 1:10. The model was to scale regarding external geometry but small details such as window frames etc. were not represented. Rear vision mirrors were omitted. The geometry of the wheelhouses was modelled. Holes were drilled between the right and the left wheelhouses to simulate the air flow through the bus chassis. Mudguards were included. The chassis was not modelled in detail, a framework of strips simulating approximately the same “crudeness” as in the real bus.

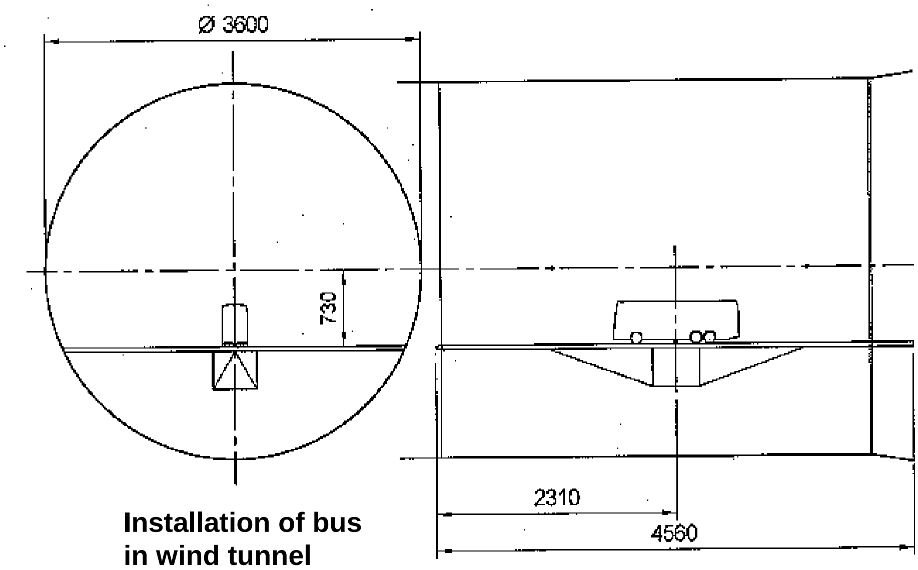
Bus model



1.15.3 *Wind tunnel, installation and measurement*

The trials were conducted in a low-speed tunnel with a diameter of 3.6 metres and a measurement length of eight metres. The model was mounted in the wind tunnel on a cylindrical support of diameter 32 mm projecting upwards through a ground plane. The model could be turned plus or minus 90 degrees in relation to the wind direction. It could also be leaned up to 20 degrees to the right. The forces acting on the model were measured with an internal 6-component scale of type 1-655 and recorded at a sampling frequency of 10 Hz. The measurements were made for wind speeds from 40 m/s to 70 m/s as a continual scan with the angle of wind incidence from –95 degrees to +95 degrees and with a turn speed of approximately 1°/s.

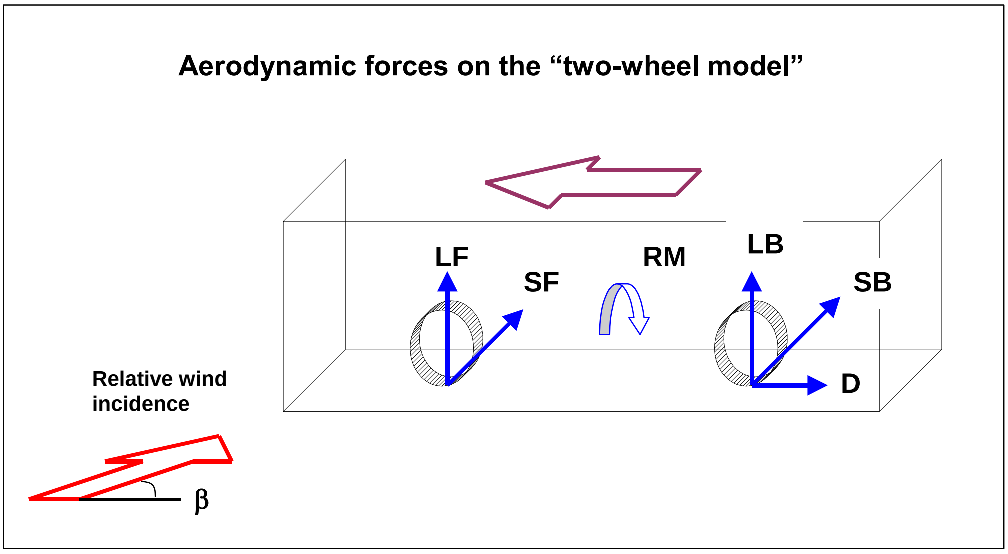
As well as measurement of forces arising, the air stream around the bus was visualised using a smoke generator. These trials were documented with photography and video filming.



Installation of bus in wind tunnel

1.15.4 *Aerodynamic forces*

A common method of studying directional stability in vehicles is to simplify the vehicle in the calculation to a two-wheel model since otherwise account must be taken of factors such as: load distribution between wheels on the same bogey, wheel suspension stiffness, non-linearity in tyre friction, etc. In the calculation model produced for the present investigation a front fictitious wheel on the bus served to represent the front wheels and a rear fictitious wheel represents all rear wheels in the bogey. The fictitious wheels are placed at the centre of gravity for the wheels they represent. See figure below.



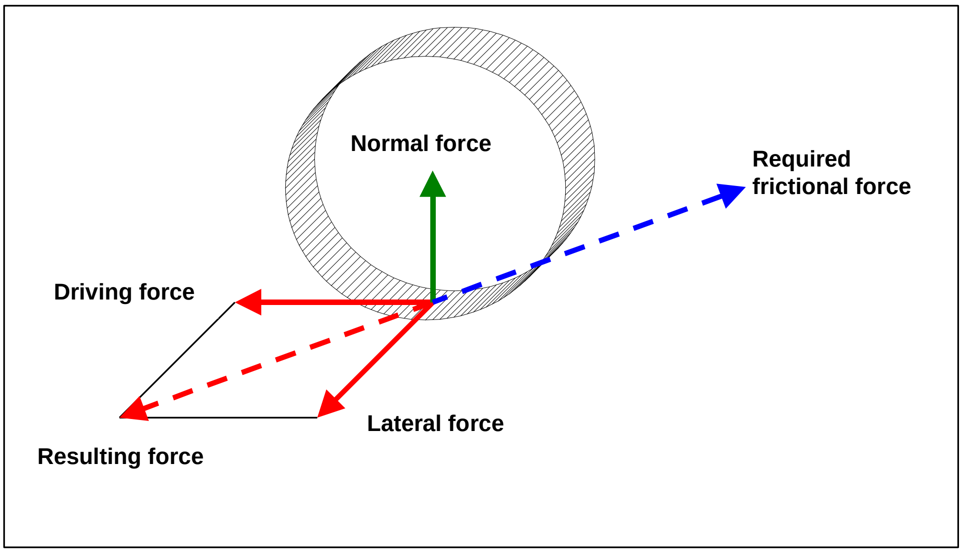
In motion the bus is affected both by the head wind and possible side wind. The resulting relative wind gives rise to aerodynamic forces on the bus which depend on the resulting wind speed and its direction, β. Once the total strength of the aerodynamic forces is known it can be calculated what this represents for forces at the contact surface between the road surface and the wheels. In the figure above the lift and lateral forces for front and rear wheel, respectively, are defined as LF and SF, and LB and SB, respectively. The force D, caused by aerodynamic resistance in the direction of travel, has been ascribed to the rear wheel since the bus is rear-wheel-driven. The aerodynamic forces also cause a torque RM about the bus' longitudinal axis, which however is of negligible significance in calculations according to the two-wheel model.

1.15.5 *Frictional forces*

It is the frictional force between the tyres and the road surface that retain a vehicle on the road and permit it to accelerate, brake and turn. The frictional force F depends on the normal force N between tyre and road surface (mass of bus distributed to each wheel) and on the relevant coefficient of friction μ according to the formula: $F = N \times \mu$. The coefficient of friction is affected by various factors such as type of road surface, coating, type of tyre, temperature, vehicle speed, etc. The covering on the road surface in the form of e.g. water, slush, snow or ice may dramatically reduce the friction coefficient. The then Traffic Safety Agency published the following guidelines for coefficients of friction:

Type of road surface and tyre	*μ*
Summer road surface	0.7–0.5
Winter surface and snow chains	0.4–0.2
Winter surface without snow chains	0.3–0.1

For a vehicle's wheels to be able to maintain their "grip" on the road surface the frictional forces at the wheel must be greater than the aerodynamic forces and the dynamic forces that may arise while the vehicle is in motion. Regarding the aerodynamic forces, in a rear-wheel-driven vehicle, the front wheels are affected only by lateral forces, while the rear wheels are affected by both lateral forces and the driving force required to overcome the air resistance in the direction of travel. The frictional forces on the rear wheels must therefore be greater than the resulting lateral and driving forces according to the sketch below.



1.15.6 Calculation model

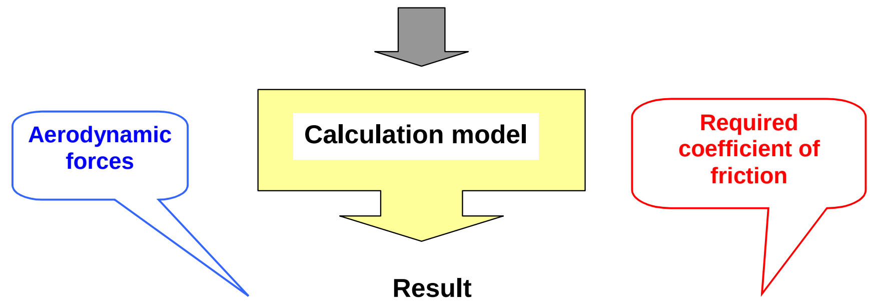
Using measurement results from the wind tunnel trials a number of mathematical models have been produced in the form of Microsoft ® Excel 97 spreadsheets where the aerodynamic forces can be calculated (simulated) for different entry data for e.g. the weight of the bus, its centre of gravity, speed and side wind. The models can also include calculation of the lowest permissible coefficient of friction on the front and rear wheel, respectively (μF and μB) for the frictional force there to be greater than the aerodynamic forces which in the most unfavourable case may arise for different loads. Although the calculation models have been based on the dimensions of the accident bus there is certain latitude in the simulations to vary both the bus' external surfaces and its wheelbase. Different calculation models have also been produced for different angles of roll of the bus.

The principles for using the calculations models are shown in the sketch below.

Starting values

Necessary friction, two-wheel model

				Test run=	117	Temp [°C]=	15
				Roll angle [°]=	0	Pressure [Pa]=	101325
V_{wind} [m/s]=	25	m_{bus} [kg]=	16720	TF [N]=	45800	S [m^2]=	10
V_{bus} [m/s]=	25	X_{tp} [mm]=	4445	TB [N]=	118223	WB [m]=	5,74



Result

ß	LF [N]	LB [N]	SF [N]	SB [N]	D [N]	RM [Nm]	μ F	μ B	μ B (+D)
0.0	2278.2	-3775.2	-109.5	-119.9	6660.8	-450.3	-0.003	-0.001	-0.060
10.0	3295.0	-3847.5	5612.7	944.7	7583.1	12608.2	0.132	0.008	0.069
20.0	5189.7	-2703.3	10761.9	3443.3	9157.6	28916.8	0.265	0.028	0.090
30.0	6718.5	146.2	15703.4	6410.4	9748.8	46175.3	0.402	0.054	0.108
40.0	7280.7	2798.2	20040.6	8755.3	8955.2	60042.5	0.520	0.076	0.115
50.0	7823.3	5036.5	24086.7	10647.5	7263.7	70696.5	0.634	0.094	0.116

E T C

1.15.7 Result

The calculation models produced permit simulation of an unlimited number of driving and loading cases. In appendix 1 the result of four simulated driving cases with the present bus type is presented graphically, with 0 degrees roll angle and with the relevant gross tare weight and in "standard atmosphere", i.e. 15 °C /1013 hPa. (The calculation model used is based on the FFA run number 117.)

Run case	*Bus speed (km/h)*	*Side wind (m/s)*
1	54	25
2	90	10
3	90	20
4	90	25

It may be seen among other things from the Appendix that the aerodynamic forces on such a bus being driven at 54 km/h (15 m/s) in an area where wind speed is 25 m/s in the most unfavourable case can create an aerodynamic lift force of just over 6324 N (645 kp) and a lateral force of 19103 N (1948 kp) on the front axle. This occurs when the wind direction resultant is just over 30°. If the bus is then unloaded a coefficient of friction of at least 0.479 is needed for the available friction force between the tyres and the road surface to exceed the lateral forces on the front wheels.

If for the same wind circumstances the bus is travelling at 90 km/h (25 m/s) the lift force can be up to 8737 N (891 kp) and the lateral force 25277 N (2578 kp) on the front axle. For the front wheels not to “lose their grip” a coefficient of friction of at least 0.676 is required.

In supplementary trials and simulations with other entry data, the following conclusions have been drawn:

– For large oblique angles of wind incidence the greatest lateral and lift forces arise right at the front.
– The forces act together negatively regarding the front wheels since the lateral force there is great at the same time as the lift force reduces the already low front axle pressure.
– The angle of roll increases the lift force for certain oblique angles of wind incidence. The effect on the necessary coefficient of friction, however, is moderate.
– When the model is modified to resemble a single-decker bus, the necessary coefficient of friction is reduced more than proportionally to the side surface.
– A simple spoiler on the lower part of the front can reduce the necessary coefficient of friction by 20%.

Visualised air flow for oblique relative wind direction

1.15.8 Future investigations

The investigations of wind forces carried out refer basically to one bus type. Further valuable information on the safety of buses in side winds can probably be obtained through supplementary wind tunnel trials. Examples of questions that could be answered are:

- Influence of bus shape. Larger radii on the forward, side and rear corners on certain bus types.
- Possible devices, type spoilers and similar, on the bus to reduce sensitivity to side winds.

1.15.9 Calculations of the actual case

Using the above calculation model SHK has calculated the necessary coefficient of friction for ensuring grip between wheel and road surface for the aerodynamic forces that may arise in the worst case. In the calculation the formula was chosen that refers to roll angle 0° and as atmospheric conditions, temperature +0.6 °C and standard barometric pressure of 1013 hPa were used.

To calculate the weight of the bus on the occasion of the accident SHK has used the standard values for passenger and luggage weights given in the Civil Aviation Administration's "Regulations for Civil Aviation", BCL-D 1.6.4. These values apply to flight with aircraft with 30 or more passenger seats. There each person over 12 years is considered to weigh 84 kilos and children between 2 and 12 years 35 kilos. According to the information available there were five children aged up to 12 years. SHK has further assumed that there was a total of 62 people on board. For the weight of the luggage SHK has used standard weights for domestic flights, 11 kg per passenger. These and other weights are reported in the table below.

Object	Calculation	*Total (kg)*
Bus kerb weight		16 720
Driver + passengers	57 x 84 + 5 x 35 + 11 x 62	5 645
Fuel	350 x 0.75 kg	262
	Calculated weight	22 627

Since it has not been possible to determine with certainty the wind speed, the bus speed and the centre of gravity when the driver lost control of the bus, several calculations have been made with different assumed values for these parameters. In addition, the design of the bus means that its centre of gravity normally moves backwards when it is loaded, for which reason calculations have been made for different centres of gravity. If for example the centre of gravity for the whole additional load in this case had come directly over the rear axles, the centre of gravity of the bus would have been moved backwards just over 7% in relation to the centre of gravity for kerb weight.

As was seen in paragraph 1.15.5 the coefficient of friction is most critical regarding front-wheel grip. In the list below, therefore, only necessary coefficients of friction for the bus' front wheels, μ F has been included.

	Speed (km/h) / Wind speed (m/s)					
Centre of gravity	90/10	95/10	90/15	95/15	90/20	95/20
According to kerb weight	0.133	0.137	0.238	0.248	0.356	0.369
Rearwards 5 %	0.164	0.169	0.295	0.308	0.445	0.462
Rearwards 7 %	0.180	0.186	0.326	0.340	0.494	0.514

Note that the above friction values apply with the most unfavourable wind direction in relation to the bus.

1.16 Other tests and investigations

1.16.1 Investigation of fire

Introduction

Following the accident the bus was towed to the Assistance Corps garage in Enköping where the investigation was commenced on 24 November 1998 jointly by SHK and the police technical department at the police authority in Uppsala. The investigation was also followed by a fire inspector from Uppsala. The bus was subsequently moved to the Scania factory where the investigation was continued on 16 and 17 December. After the police had concluded their technical investigation SHK continued its own investigation. This was directed primarily at attempting to find why the engine revolutions increased after the collision with the culvert. This could possibly explain the start of the fire and the initial course of its spread.

Coachwork and passenger compartments

It was quickly discovered that the fittings in the upper-deck passenger compartment were for the most part totally destroyed by the fire. Parts of the roof had also been burned away. On the lower deck there remained only some heat-affected and sooty seats, while the others were severely damaged by fire. In addition there was fire damage on the left-hand side forward of the left front wheel as far as the door behind the driver's seat, (see picture, section 1.13.2). An almost undamaged double seat was preserved for later fire trials.

Externally the bus' right side that had lain on the ground during the fire was essentially undamaged. As against this, the area of the lower deck in front of the front wheel had been crushed.

Apart from mechanical damage, the front of the bus was severely burned. At the rear, the engine compartment hatch was burned away and the rear outer wall of the bus had totally burned up.

All luggage compartment hatches and the adjacent technical spaces were undamaged on the outside.

Luggage compartment

Prior to commencement of the investigation, as mentioned, the luggage had been unloaded, while the ordinary bus equipment had been left. Among other things a loose transformer for transforming 24-volt battery current to 220-volt AC current was found. This was so that a normal industrial vacuum cleaner could be used for cleaning the bus.

In addition a bag of reserve V-belts was found. Several plastic jerry cans with different contents including dilute antifreeze, concentrated and dilute windscreen washer fluid, motor oil, disinfectant for the toilet – marked inflammable – and methylated spirits were found. Some of the jerry cans had been damaged in the fire and the contents had leaked out. A bale of toilet paper was also stored in the compartment.

Engine compartment

The investigation of this compartment was documented by the police.

The most extensive fire had occurred in the rear right-hand part of the bus.

Since the engine was rear-mounted, the transmission line consisting of clutch, gear box, transmission shaft and rear axle drive ran forwards from the engine. The first engine cylinder was thus rearmost and the sixth furthest front. On the left-hand side of this sixth cylinder there was a large hole and also one on the opposite side of the cylinder. On this side there was also a hole in the engine block and one in the oil sump. Through these approximately 25 litres of engine oil had run out. According to the investigation report the oil was judged to have had a temperature of at least 100 °C.

Closer examination of the sixth cylinder showed that a connecting rod had broken loose from the crankshaft. The bearing cover fixing the connecting rod to the crankshaft was missing, as were the bolts that held these parts together.

Furthest forward on the right-hand side of the engine there was an oil pressure sensor for converting oil pressure to an electrically measurable value. Electric cables entered the top of this sensor. The plastic mounting around these was missing and hence a small hole through which oil could spray out at high pressure as long as the engine was running. On the engine block above the sensor there was a burned-on coating which according to the technical report suggested that oil had sprayed out there.

The engine oil in the oil sump was sucked up through an oil filter. When the bus landed on its right-hand side the oil ran away from this filter and the circulation of oil ceased. In the oil sump, metal shavings and parts of the crankshaft bearing were found.

According to the investigation report the engine damage had not caused the engine to stop. According to information received somebody had turned off the engine with the key. This bus engine, however, could not be stopped with a key, but, as mentioned earlier, with a button.

According to the investigation report the reason for the engine damage was either that the engine had over-revved or that the piston in the sixth cylinder had seized up. The latter can have come about if, for example, water had entered the cylinder; but there was no sign of this. It was more probable that the engine had over-revved. The hand accelerator control was fully out. The driver stated that he had not touched the hand accelerator during the drive. However this accelerator control was so placed that some part of his body or clothing may have got caught in it when he was ejected through the front windscreen.

On the right-hand side of the engine between this and the compressor there ran fuel lines of plastic material. Together with these the electrical leads were combined in a bunch. All this was arranged along the right frame alongside the engine. To the rear of the engine compartment above the V-belts to the fans, etc., the water separator with its glass collection jar were placed. Through this all fuel passes on its way from the tank to the injector pump on the engine. There was no damage to the steel fuel leads. Approximately 70% (tank volume 400 litres) of the contents of the tank remained, however, after the fire. The fuel lines entered the tank on the right-hand side, which allowed fuel under atmospheric pressure to run out through damaged lines when the bus was in the ditch.

The rear left-hand engine mounting was defective even before the accident. When the bus overturned, the cooling plant compressor had fallen down to the ground since it stood on rubber feet not intended to resist tensile forces.

The part of the bus electrical system in the engine compartment and its vicinity was particularly closely examined. Electrical cables in the area of the fire were damaged externally by the fire. One lead had fallen down from its mounting and been cut off against a V-belt pulley. The fracture surfaces showed no sign of any short-circuiting. The lead was between a connection box above the compressor and the engine. It was not connected at either end. As against this, overloading damage in the form of melted drops was observed on its cable terminal, which was found close to the rear of the engine.

The plus cable to the starter motor was damaged at its connection to the motor. About one-third of its strands were loose at the connection to the cable terminal. They had been cut, torn or burned off. At the fracture surfaces there were melt drops that may be overloading damage.

On the earth cable (minus lead) cable terminal, the seating of which was beside that of the plus cable, there was overloading damage. This may indicate that some conducting object had landed between the electric cables, with overloading and arcing as a consequence. This overloading may have taken place in connection with the fracturing of the engine block. The two adjacent holes in the engine block were near the starter motor. In one of these, there was a deformed part of the crankshaft bearing. If one of the engine parts ejected from the block had temporarily landed across the electric leads, hot engine oil may have leaked out at the same time. Even the disconnected electrical lead mentioned earlier with overload damage on its terminal may, during the course of the accident, have come into contact with the mounting of the plus lead in the starter motor and started a cable fire.

The batteries were removed and neither they nor the connecting cables exhibited the type of damage that arises following protracted short- circuiting.

In a fairly small electrical lead running to the engine heater there was slight overload damage adjacent to the connection to the pole. According to the investigation report the damage was limited and cannot have started the fire.

The V-belts on the bus were examined. They exhibited no sign of having had anything to do with the start of the fire.

In addition the bus' diesel-driven engine- and compartment heaters were examined, but they were undamaged. Exhaust from these went out behind the left-hand rear wheel mudguard. The area round the exhaust pipe aperture was dirty and damp, while the actual aperture was dry. The bus driver has stated that the heater had not been switched on during the journey.

Along the left-hand side of the bus ran two oil-cleaning pipes from the engine block. At both their mountings there was oil leakage and the engine block was coated with dirty engine oil. One of the mountings was loose to the touch. On the same side was the injection pump. The accelerator axle mounting leaked diesel oil and when the axle was moved a small quantity of diesel sprayed out.

On the front of the engine block two fuel filters were mounted. Small quantities of diesel had run out mainly from one of these. The marks from this, however, went vertically and according to the investigation report they probably arose before the accident. The fuel filters also showed only vertical marks.

The upper part of the engine exhibited no significant fire damage. There was no leakage around the fuel nozzles.

It was discovered that the supercharger air cooler of the bus engine was seriously blocked. According to the investigation report this can have contributed to a raised inlet air temperature.

In the investigation report the possible course of the fire was summarized. The gist of this is given here.

When the bus overturned, the engine continued to run at high revolutions. It then lost oil pressure since the filter came above the level of oil. The sixth-cylinder crankshaft bearing and the last main bearing failed, with the consequence that its connecting rod was torn loose from the crankshaft. Bolts and the bearing cap were torn away and presumably ejected from the engine.

Probably, portions of the block were thrown out to the right onto electrical cables to the starter motor, cutting off parts of the cables and causing short-circuiting. At the same time very hot engine oil that had run out started to burn. The cables and the dirt caught fire. Possibly the fuel lines also became damaged.

According to the experts this scenario led to two alternative theories as to how the engine compartment fire proceeded.

Alternative 1

Diesel and engine oil burned more and more and if the engine was still running oil was forced out through the holes in the engine. Some of the oil was atomised at the oil pressure sensor, which was damaged and releasing oil. Hot diesel in the return line may have been pumped to the source of the fire by the dying engine. After the engine had stopped, atmospheric pressure in the fuel line remained until the partial vacuum in the tank stopped the flow together with blocked, fused lines.

Alternative 2

The cooling plant compressor, with a weight of 80–90 kg, loosened and pinched off the cables at the generator. This caused a short-circuit near the running diesel and the oil from the smashed water separator glass collection jar. Apart from the holes in the block and the oil line, oil lines to the servo pump were also burned.

Freon hoses were crushed and damaged. These may also have been involved in the development of the fire. There was still full voltage in the battery cables, starter motor and generator, and in the rear electrical terminal box from which the bus engine could be started and stopped. This terminal had several cables that may have been pinched/broken off/torn out thus starting the fire. Concentrated windscreen wiper fluid which may have run out from leaking jerry cans in the cleaning compartment above the engine compartment may also have contributed.

The coolant, designated R 134 A, used in the air-conditioning plant was inflammable. The quantity was 20 kg and it was contained partly in the tank in the engine compartment and partly in the condenser. The latter was situated above the engine compartment. The whole condenser was exchanged in connection with renovations on 24 August 1998. It was filled with coolant at the same time. Current regulations regarding the handling of freon mean that the plant must be checked at certain intervals by an inspector authorised to do this. The compressor was not renovated or exchanged at this time. The reconditioning had been carried out by Tunby Kyl AB in Västerås. The air conditioning plant had a safety valve opening at a pressure of 24 bars.

An expert who was consulted has also communicated the following. When the hoses failed there was violent development of gas in the fire area and a great increase in the pressure in the gas system. The safety valve was probably unable to relieve the pressure which may have risen to 30 bars during the fire.

In connection with this the experts noted that the cooling fluid containing glycol from the hole in the engine block may have ignited.

The bus compartment heater, which ran on diesel, may have been involved in the fire provided that it was switched on. The heater burned with an open flame and large quantities of oil gas were within its reach. It has not been possible to establish whether the heater was on when the bus left the road. According to the heater supplier the exhaust pipe was free of road dirt at its outlet, which may indicate that the heater was on during the journey.

The supercharger air cooler cell packet was blocked in a number of its cooling cells, partly hindering the air flow through this. The radiator of the normal water cooler was however clean and in relatively good condition, but inlet air to this packet was also choked by the impaired air flow through the supercharger air cooler. The engine temperature was probably not greatly affected, provided that the bus heating system was being used fully. On the other hand the inlet air was less cooled on warm days.

The frame of the engine oil pressure contact had exploded and oil pressure thus disappeared entirely. Moreover, oil pressure had previously started to sink since the inlet side of the oil pump had come above the oil level in the sump when the bus overturned. The lack of pressure had as a consequence that no oil spray came out through the damaged oil pressure sensor.

The rearmost left engine mounting had been faulty for some time. The engine therefore tipped easily when the bus overturned and the lateral motion of the engine may itself have been the cause of the failure of cables, lines and hoses.

The heating system fans were probably on and may have increased the spread of smoke to the passenger compartments.

Before the engine was removed from the bus during the investigation, a serious oil leak was discovered where the pressure oil tube entered the engine. A pressure oil tube transports oil for lubrication, cooling and cleaning.

The accelerator linkage on the injection pump (high pressure) for the fuel had leaked fuel axially. Leaking fuel had run towards the exhaust manifold. One of the fuel filters had leaked diesel before the bus started to burn.

The investigation report concluded as follows: "It emerges clearly that the most severe fire damage is in the right-hand part of the engine, the part that was nearest the ground after the bus overturned. The reason for this is that all the hot engine oil ran down to the ground in this area and ignited. At the scene of the accident there was a heavy wind which prevented the fire from spreading upwards into the engine compartment. Instead the fire took hold in the fibreglass-clad rear wall of the bus and supersaturated fire gases spread into the bus. The fire gases probably also came in through the ventilation system. Inside the bus these were mixed with the available air oxygen and rapidly reached a favourable mixture with ignition as a consequence."

1.16.2 Technical investigation from traffic safety viewpoint

The vehicle was examined from a traffic safety viewpoint as requested by the police authority in Uppsala. This check was carried out by two vehicle inspectors. The investigation included systems for wheels, steering, braking, manoeuvring and communication. To quote the summarizing conclusion: "During the examination nothing emerged to indicate that the vehicle had any technical fault that can have contributed or caused the accident".

1.16.3 Fire testing of bus seats

Since it had not been possible to evacuate the bus before the fire rapidly spread into the passenger compartments, it was important to establish how far the bus fittings had such properties that they contributed to the rapid ignition.

During the past three decades several fire testing methods have been used to attempt to classify material. These methods were originally developed against a background of experience of fires in wood and wood-based materials and products. The methods do not meet basic requirements on giving information regarding properties or phenomena that are functionally and distinctly defined. When new material types are used – particularly plastics – the tests have often proved to give incomplete information and not infrequently directly incorrect basic data for judging the behaviour of materials and surface coatings under real fire conditions. As early as the beginning of the 1960s, comparative trials were run in six European fire laboratories in then Western Germany, Belgium, Denmark, France, Holland

and England in co-operation with the ISO (International Standardization Organization). All the test results, covering 24 different materials, were then collated and proved to exhibit a remarkably large spread in their results. The surface material that according to one country's test standard was considered the safest was ranked as the most risky of all the 24 materials according to another country's standard.

Within Europe a standardized test method was produced for testing upholstered furniture, which was intended to be jointly applicable in the participating countries. However, this was not the case, partly for trade-political reasons. For its own investigation, SHK elected to use this method. The tests were carried out by the Swedish National Testing and Research Institute in Borås (SP).

The object to be tested was an almost undamaged double seat from the burned bus. The seat had in fact been exposed to the effects of smoke and heat during the fire. Only a fairly small surface in the form of soot on one seat distinguished it superficially from an undamaged seat. The seat was placed on a weighing platform and ignited on the sooty seat and back cushion with a gas burner. The burner produced an effect of 30 kW. The ignition sequence continued for two minutes. Smoke gases formed during the burning were collected through a hood placed above the object being tested. Using measurements of oxygen consumption, the heat effect developed was calculated. The smoke was measured using a lamp (white light) and a photocell mounted in the smoke gas channel downstream from the hood.

As shown in the report from the trial, the maximum heat effect developed was 316 kW. Total released heat energy during the trial was 252 MJ (megajoule or one million joules). The average effective heat of combustion was 21.4 MJ/kg. Maximum heat radiation was 3 kW/m^2.

The measured heat effect from the fire trial gives information on people's possibility of evacuating and on the risk of further spread of fire. For a double seat to be able to cause ignition in a fairly small space (approximately 10 m^2 floor surface) with an open door requires that the fire gives off a heat effect of 1000 kW. In this trial this effect was not reached.

The test showed that the maximum heat effect of about 300 kW was distributed over two peaks, at just over 5 and just over 10 minutes after ignition. First the large proportion of one seat burned up and thereafter the other, with the same maximum effect.

SP stated in their report that the fire gave an effect of 200 kW after approximately 3.5 minutes. Subsequently a relatively slow increase in the fire was measured where the next stage was a spread to the other seat. According to the report this means that rapid growth of fire in a real case with this type of seat therefore requires that other combustible material is in the vicinity.

SHK has in its investigations of bus fires RO 2000:1 and RO 2001:1 established that in both cases the bus seats alone would have been able to achieve ignition.

1.17 The bus companies

Västanhede Trafik AB is a family company with its headquarters in Avesta. On 5 April 1988 the company obtained permission to carry out road passenger transport on contract, limited to transport within Avesta municipality. On 1 January 1989 the right for the granting authority – the county council – to limit permission to applications only within a certain area in the county, was abolished. An organization with road transport contract permission today thus has the right to conduct transport anywhere within the county.

At the time of the accident the Dalarna county council register of professional traffic vehicles listed 11 buses and four taxis in the company's name.

To run regular traffic across county-council borders, permission is required from the National Road Administration. For this bus line, it was Säffle Reseservice AB that had permission to conduct passenger transport at weekends, Friday to Sunday, on the routes Falun–Borlänge–Stockholm, Orsa–Stockholm, and Idre–Stockholm. Västanhede Trafik AB had been employed legally as contractor to run the traffic.

2. ANALYSIS

2.1 The skid

The driver experienced that the bus “was being pressed” off the road and that it was impossible to steer it back onto the road. The stretch in question was largely straight and basically without a slope in the direction of travel. According to the measurement of the road surface made after the event, the camber was well within applicable limits, both before and along the skid. No technical fault on the bus that could explain the course of events has been discovered.

The bus left the road on a stretch running through open fields. At the time of the accident there was a strong gusty side wind from the left and the road surface was covered with wet snow. It emerges from the investigation ordered by SHK regarding lateral wind sensitivity in a tall double-decker bus (section 1.15) that large aerodynamic lift and lateral forces can arise in certain situations. These forces combine particularly negatively regarding the front wheels, since both lateral force and lift force there are greatest at the same time as front axle pressure is low. It is therefore important in this case to attempt to obtain an idea of what the lowest necessary coefficient of friction between the front wheels and the road surface is before the front wheels “lose their grip” because of the wind forces that can arise.

The calculation models produced for the bus type in question allow great variations regarding values of the input parameters. In calculating the necessary coefficient of friction in the present case (section 1.15.9) it has been possible to determine some parameters with considerable certainty while others have been more uncertain. For this reason many calculations have been conducted with different input values for the centre of gravity of the bus and its speed, together with prevailing side-wind speed.

The analysis by the Swedish Meteorological and Hydrological Institute (SMHI) of the weather situation, together with witness information from the site, indicates that the speed of the wind gusts was at least 15 m/s. The wind struck the bus from the side, so that the resulting wind direction may very well have been around 30°; an angle of incidence that has proved unfavourable with respect to undesirable aerodynamic lift and lateral forces. According to the bus’ tachograph its speed before the accident was between 90 and 94km/h.

With these input values for wind strength and bus speed the calculations show that the front wheels even in a 'neutral' centre of gravity position, could have lost their grip on the road if the coefficient of friction was lower than about 0.24. If in addition the bus was 5% back-loaded, a coefficient of friction of just over 0.30 would have been necessary to ensure front-wheel road-holding. If the wind speed in the gusts was 20 m/s for a neutrally loaded bus, friction of just over 0.36 would have been needed.

These values apply only for the aerodynamic forces on the bus. To this must be added the friction force required because of the camber of the road and for possible dynamic forces in connection with braking, turning etc.

Since the road surface was covered with wet snow this as regards friction may be equated with 'winter road conditions and snow chains' and according to section 1.15.5 would have involved that a coefficient of friction was only of the order of 0.4–0.2. If these available friction values are compared with the friction probably required according to the above, an obvious risk emerges that the front wheels may lose their grip on the road.

Everything therefore suggests that the bus, during the drive in the gusty side wind, momentarily became unmanageable in consequence of the front wheels losing their grip on the road surface. For this reason the driver was unable to regain control before the bus skidded out on the sloping verge and overturned.

The fact that the bus finally collided with the culvert, whereupon the front window-panes were pressed out must be ascribed to fortunate circumstances, since the normal evacuation routes were blocked. Had this not happened the consequences for those on board would in all probability have been devastating.

2.2 The fire

The fire started in the engine compartment as a consequence of the bus overturning. The engine continued to run for some minutes at high revolutions. Because of the failed lubrication since the suction filter to the oil pump lay sideways above the oil level, and the increased friction this caused, the engine was damaged mechanically so that the connecting rod smashed the engine block and the oil sump. Through the holes therein hot engine oil then flowed out.

There are several different ways the fire may have started. An electric arc may have formed, or engine fuel, or engine oil may have come in contact with one or other of the hot surfaces on the engine, e.g. the exhaust manifold or the turbocharger.

What suggests an electric arc is among other things the melt drops found on the terminals of the electric cable lying loose in the engine compartment. This may well have been in simultaneous contact with a battery pole and earthed this onto the chassis. There were also indications that an electric arc may have formed through the pieces of engine block that were smashed loose coming into contact with the starter motor electrical terminal, on which there were melt drops. Damage to the connecting cable in the form of frayed strands on the starter motor cable terminal may itself have caused melt drops on the starter motor. However, it may also indicate that an arc came about through conducting material coming into contact with the plus pole and an earthed part simultaneously. The connecting lead to the starter motor is normally un-fused. An arc of this nature may easily ignite both hot engine oil and leaking fuel.

The position of the fuel lines in relation to the hot engine parts made it possible that fuel could run down onto these when the bus overturned. Leakage may have started when the water separator collector glass was damaged.

The investigation further showed that the left-hand engine mounting was defective prior to the accident and that the air-conditioning compressor came loose as the bus ran along the ditch. This caused the engine and the compressor to touch one another in such a way that fuel lines and water separator collector glass may have been damaged, causing leakage. If the return fuel line from the engine to the tank had ruptured, the supply of fuel to the engine would not have been affected, but the leaking diesel fuel contributed to the fire. The fuel line here was of plastic material.

A fire in the engine compartment would have affected the return fuel line almost immediately so that large leakage would have arisen, approximately 8–9 litres per minute at full revolutions. It would have been even larger if the fuel had run backwards from the tank. The leaking fuel may very well have made its way into the hose leading combustion air to the engine. This would have led to the engine speed increasing irrespective of acceleration and the supply from the injection pump.

The engine thus ran at high revolutions. Since it was lying on its side the suction filter to the oil pump came above the oil level and lubrication oil circulation stopped. The poor lubrication and the high revolutions led to the friction between the piston and cylinder wall in the sixth cylinder becoming so great that the piston was braked in its movement, while the crankshaft continued with largely unchanged revolution speed. With the increased friction the piston became hotter and its volume increased which in turn led to increased pressure against the cylinder wall. When the piston seized against the cylinder wall the connecting rod bearing cover failed and was slung out, making a hole in the oil sump. Freed from the crankshaft, the connecting rod then smashed a hole in the engine block with the impact it received from the connecting rod throw, since the other cylinders were still turning the crankshaft. Through these holes, hot engine oil then flowed out.

The fire in the engine compartment caused the collector glass to break after a minute or so because of the internal vaporization pressure, increasing heat stresses in the glass. If the collector glass had been smashed directly when the bus ran into the ditch, the engine would soon have stopped through lack of fuel since the quantity in the filter and the pump was too little and air would have entered the fuel system. It would have been impossible to keep the engine running for several minutes. After a brief fire the engine would have stopped through lack of fuel anyway through the damage to the fuel line and the fact that the collector glass had disappeared.

In view of the relatively short time that elapsed after the bus stopped before the fire must have started, SHK judges that the most probable cause of fire was that the return fuel line was damaged when the bus overturned and that the leaking fuel was ignited. The increase of friction in the sixth cylinder cannot have entailed engine damage until some time after the lubrication had failed. Thereafter further time must have passed before the fire achieved any significant proportions.

The fire in the engine compartment soon made its way out into the open air since the engine compartment hatch became burnt through. Thereafter the rear wall of the bus was ignited and through this an opening was created into the passenger compartment. Flames and unburned gases were forced by the wind into the passenger compartment. The unburned gases were ignited since the availability of aerial oxygen in the compartment was good.

Even though the fire trial showed that the development of heat effect in the actual bus seats was insufficient for ignition, the heat effect development from the unburned gases from the bodywork and the fire in the engine compartment were sufficient for rapid ignition.

2.3 The rescue services

When the emergency services centre (SOS Alarm) was informed of the accident, no fire had been noted. The calling-out of the rescue services thus followed the alert list then in force for “large accident site”. When the information arrived that the bus was on fire the Fjärdhundra rescue services station was not alerted immediately which, according to the alert plan, should have been done. To ensure that such a “miss” does not occur again, the alert procedure has been modified as reported in section 1.4.

As previously mentioned the delayed alerting of the rescue force from Fjärdhundra probably had no negative effect upon the rescue operation. The part-time staff there have a longer turn-out time than a force of full-time staff, and the force from Enköping arrived at the scene of the accident as early as 18.50h, i.e. 13 minutes after receipt of the alert from the emergency services. In addition all those on board were by that time out of the bus except for the lady who had got stuck. Once she had been helped out the fire was fought by two firemen while the other staff concentrated mainly on caring for and supporting those who were injured.

With the exception of what has been mentioned above, the alerting, as far as SHK can judge, took place rapidly and efficiently and the necessary resources were called out. These made their way to the scene of the accident as rapidly as circumstances permitted. Care of the passengers, which was also done with the assistance of volunteers, appears to have been conducted as well as the resources allowed.

In this connection, the contributions of the driver of bus 2 and his ten helpers must be stressed. Their boldness and rapid intervention prevented the accident from having worse consequences than it in fact did.

2.4 Medical aspects

The majority of personal injuries were not caused by the fire directly but were of a more mechanical nature. In a study of how the people were injured it emerged once again that people sitting furthest forwards in a bus are affected very hard by a collision. When the bus left the road, fell over on its side and collided with the culvert, these people were ejected together with, or possibly through, the window panes. It also emerges that the upper-deck passengers were subjected to a more violent blow to the right side of the body, with neck and back injuries as a consequence. When the bus overturned, those who were sitting there were further out upon a lever arm and subjected to greater force on impact with the ground than those who were on the lower deck. Those who sat on the left-hand side fell onto those who were on the right-hand side.

The course of events once again raises the question of safety belts in long-distance buses. Would such belts have been able to prevent or alleviate the personal injuries. In SHK’s view a simple safety belt would probably have prevented the forward passengers and the bus driver from being thrown out. Further, those sitting on the left hand side would probably not have fallen on to those on the right. As against this, safety belts would hardly have been of use against the injuries caused by the lateral force arising when the bus overturned.

The fact that everyone in the bus was saved must naturally firstly be ascribed to the contribution from bus 2. It was also significant that the fire did not take hold more quickly. A not-unimportant contributory cause was also certainly that the majority of those on board were relatively young. Only eight of those were over 60 years and none had reached 70. In a similar accident with a majority of elderly passengers the number of deaths and serious casualties would probably have been large.

Regarding medical care, physicians from UAS have advanced certain views that the most seriously injured were transported to the hospital in Enköping, which lacked preparedness for surgical operations during weekends. It has been considered that there was thus a delay in definitive care. At the hospital in Enköping, however, resources for qualified medical reception were mobilised rapidly, and the hospital is significantly closer to the scene of the accident than UAS is. The first ambulances, including the command ambulance, were stationed in Enköping and for them it was natural to use this hospital. By sending the first ambulances to Enköping these could return relatively quickly to the scene of the accident. The first ambulance to arrive at the hospital also took the two medical teams to the scene of the accident. The extent of injury could, moreover, be assessed at the hospital and the casualties prepared to withstand transport to more distant hospitals with larger resources. The intention was not that more extensive investigations and treatment were to be carried out at Enköping unless considered necessary. For longer emergency transport, the weather conditions and the poor road condition must also be taken into account.

As mentioned previously, it does not lie with SHK's area of responsibility to assess medical measures and treatments. However, SHK finds it reasonable that under prevailing conditions the ambulances used Enköping hospital when removing the most serious casualties from the scene of the accident.

The hospital staff experienced some shortcomings regarding external activity. Questions regarding where the casualties had been taken could not be answered in many cases and it was not known, for example, where within the police force this information was being handled. Perhaps the authorities involved should examine whether circumstances in this respect are similar at other hospitals. Should this prove to be the case simple routines should be worked out to eliminate such shortcomings.

2.5 Wind forces on buses

The examination described in section 1.15, as mentioned, showed that tall double-decker buses driving in strong side winds may be exposed to such large aerodynamic lift and lateral forces that the front wheels may lose their grip on the road in e.g. normal winter road conditions. When this occurs there is a great risk that the bus is forced off the road or over to the opposite side without the driver being able to prevent this. This can happen with a bus in good technical condition, entirely without warning, during normal driving on a straight and well-prepared winter road. Those on board and other road users may be exposed to a great risk in this way. Apart from the bus' aerodynamic shape it is predominantly the state of the road, the strength and direction of the side wind, the bus' speed and its weight and centre of gravity that are decisive as to whether a risk exists.

As mentioned earlier it appears that no or only very little research has been done in this area. Inspection authorities, bus operators and drivers have therefore probably limited knowledge of the problem and what may be done to solve it. Nor has SHK found any special instructions or restrictions regarding driving in heavy wind.

Since a driver himself is able to affect several of the factors of importance in this connection, SHK considers it a matter of urgency that the instances affected should be informed of this circumstance. Suitable instructions and restrictions should also be produced for driving with specially wind-sensitive buses in heavy wind.

The bus type in question is often used – as in the present case – for regular traffic over long distances where the pressure upon drivers to follow the timetable is great. Even though many drivers through their professional skill presumably have a “feeling” for how the bus should be driven under these weather conditions, it may in practice be difficult to, e.g., lower speed sufficiently. If a driver lowers his speed sufficiently he/she risks not arriving in time, with the accompanying risk of complaints from both passengers and operational management.

In commercial aviation there have long been written restrictions on when pilots may take off and land commercial aircraft with respect to severe wind and runway conditions. It should be possible to produce similar aids for bus drivers to use when e.g. determining maximum permissible speed and suitable load distribution in the bus, based on prevailing road conditions and wind strength along the route. A regulation of this type would assist drivers in adapting their driving to troublesome weather conditions, leading to safer traffic. Temporary operational restrictions of this type, with respect to road safety, would probably be accepted by most passengers and operators. It would also lead to greater understanding and acceptance of the fact that timetables cannot always be kept. A reservation concerning this could be included in the timetable or also the journey time given could be lengthened.

There are great differences in the shapes of buses, their areas of use and the ways they are driven. The most realistic approach would therefore be to delegate the responsibility for producing such regulations to the bus companies involved, together with the responsibility of training the company’s drivers and ensuring compliance with the regulations.

2.6. Safety aspects

Since the bus driver was ejected from his bus in the accident and injured, the difficulties were increased for the passengers. A driver should have knowledge of the various technical systems in his bus and also some training in how to act in the case of a bus fire or other accident. An important part of a driver's function in connection with an accident is to call for help. This was handled in the present case by the driver of bus 2 who fortunately came on the scene immediately.

If the driver of the accident bus had been able to, he would probably have stopped the engine as an early measure, and this may possibly have prevented the outbreak of fire. Had this been the case at least some of the personal injuries could have been avoided. This applies not only to the smoke and burn injuries, but also to some of those that occurred during the rapid evacuation necessitated by the fire.

A common aid to emergency evacuation from buses is to provide them with glass-breaking hammers. These are specially designed so that a passenger can break a hole even in a safety glass window-pane. The tool can hardly have any other use than to break window-panes. In spite of this (or perhaps just because of this) they are so sought after that it is unusual for all glass- breaking hammers to be in place in one bus. To prevent pilfering, each hammer was fastened to the bus with a thin steel wire. This however did not help. The wires were cut or torn off. This conduct SHK considers very serious since the lack of hammers represents a safety shortcoming. As noted earlier, what may have happened in the present case, if the front panes had not fallen out? It may be noted here that newly-manufactured buses these days have bonded panes that are more firmly fixed than those in the accident bus.

A bus may be viewed as public premises on wheels. Even when a bus of the present design is at a standstill on the road problems arise in rapid evacuation because of the narrow stairs from the upper deck and the otherwise narrow passages. The limited internal volume means that even a fairly small fire can rapidly fill the bus with smoke, further impeding evacuation. It is therefore urgent to delay for as long as possible the effects of a fire in, as in the present case, a rear engine compartment. It may be noted in passing that the majority of all bus fires have started in or near the engine compartment. As the present case shows, the low fire resistance in the rear wall and adjacent exterior walls of today's buses means that a fire in a rear-mounted engine compartment can rapidly spread to passenger compartments. Consequently, protection for those on board may be increased by reinforcing the fire resistance in these parts of the bus.

SHK has in two final reports on bus fires (RO 2000:1 and RO 2001:1) drawn attention to the need to install, in engine compartments situated far from the driver's seat, an automatic fire alarm system and a fire-extinguishing device. Even though, as in the present case, the engine compartment is relatively easily accessible there is always an obvious risk of personal injuries to any private person who opens the engine compartment hatch and attempts to attack the fire with one of the common models of fire extinguisher. In the cases earlier investigated by SHK people who have attempted to extinguish fires have realised this danger and therefore sprayed fire extinguishing agents through grids and cracks.

Regarding the fire resistance of the material in the rear part of the bus it suffices to note that appropriate fire insulating material can be mounted in such a way that it remains in place during a fire. Any windows there may be at the rear of the bus may indeed serve as evacuation routes, but in the case of an engine compartment fire these also represent a danger. Affected by fire, the glass may rapidly shatter and fire gases may penetrate. From the point of view of fire protection, therefore, windows at the rear of a bus of this type should be avoided.

Against this background SHK would stress the following.

It appears particularly important for the Swedish National Road Administration, now together with Swedish Rescue Services Agency, to attempt to find safe solutions for the emergency evacuation of buses. This concerns the possibilities for those on board to make their way out themselves and the knowledge and ability of municipal rescue services to enter from the outside. As an example in the latter respect, in SHK's investigation preceding the above report RO 2001:1 it turned out that the rescue services had not been able to break open the front window. Problems associated with the difficulties of rapid evacuation should also be particularly noted in the design and type approval of new vehicles. Here other bus types such as handicap buses should be also included, as witness the recent tragic accident when a handicap bus started to burn. A person with a handicap who was travelling in the bus died since it was impossible to open the back doors, which were blocked by the raised hoist ramp.

Regarding fire alarm and fire extinguishing equipment in engine compartments SHK refers only to what has been stated in the earlier reports.

Aspects of safety are also the condition and maintenance of a vehicle and the goods accompanying occupants on a journey.

In the present investigation of the bus it was discovered that an engine mounting had long been faulty, that the supercharger air cooler was partly blocked and that disconnected electric leads had formed a pile near the rear electrical terminal box. These shortcomings should, in SHK's view, have been discovered during normal maintenance and dealt with.

The number of jerry cans and bottles of various inflammable fluids carried in the bus luggage compartment should have been stored in a more secure manner in marked racks or holders, or been anchored in some other way. Loose lying containers themselves imply a risk. Leaking inflammable fluid can lead to fires that are difficult to extinguish. A fire in a luggage compartment may be hard to discover. It may therefore continue for so long that the fire extinguishers normally found in a bus are unable to extinguish it.

Insofar as the observations now reported do not represent exceptions to the vehicle park of this company, this may indicate certain shortcomings in the company's conception of safety and service.

3. CONCLUSIONS

3.1 Result of investigations

a) The driver was duly licensed to drive the vehicle.
b) The bus had been approved at the latest inspection.
c) No technical fault has been found in the bus.
d) Strong and gusty side winds prevailed.
e) The road surface was covered with wet snow.
f) During driving in side winds large aerodynamic lift and lateral forces arise upon buses of the type and size in question.
g) In strong side winds it is normally the front wheels that run the greatest risk of losing their grip on the road.
h) Fire started in the engine compartment.
i) It has not been possible to establish to cause of the fire with certainty.

3.2 Causes of the accident

The skid was probably caused by the bus, while being driven in strong and gusty side winds, momentarily becoming uncontrollable as a result of the front wheels losing their grip on the road.

It has not been possible to establish with certainty the cause of the fire in the engine compartment.

4 RECOMMENDATIONS

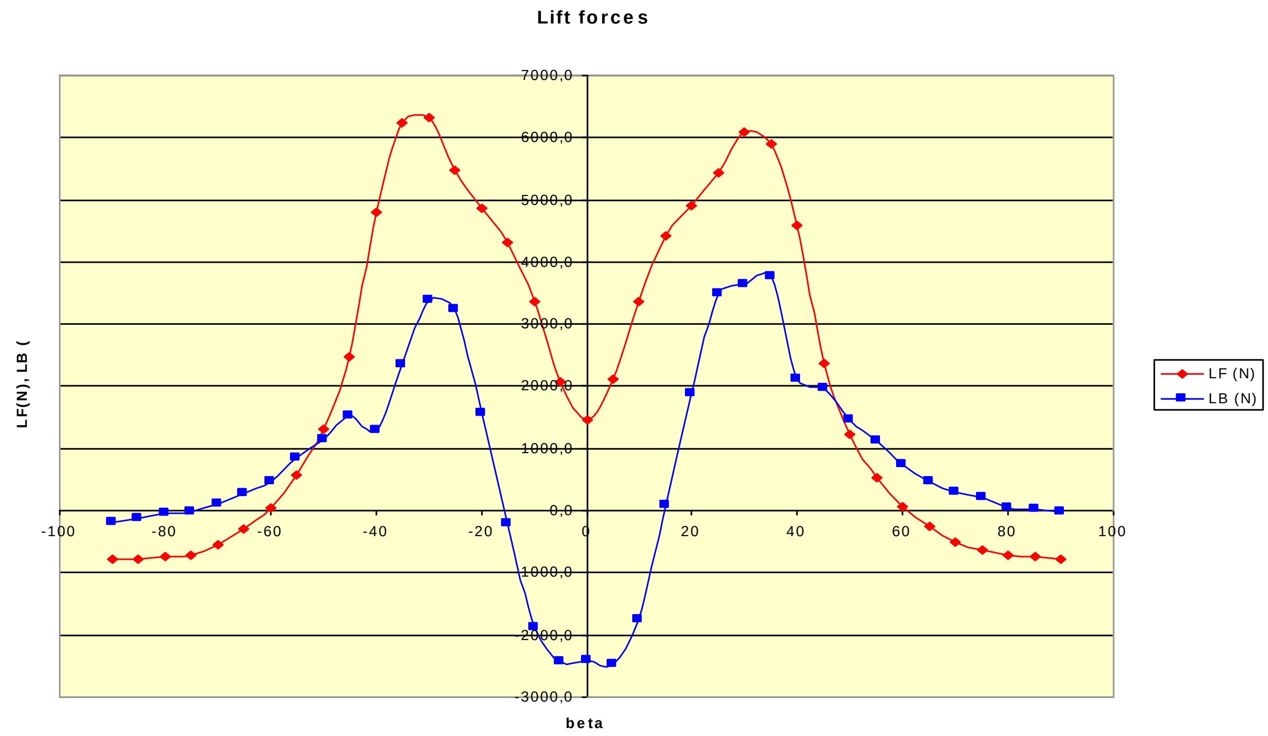
a) The Swedish National Road Administration is recommended to inform the appropriate operators and vehicle manufacturers in a suitable manner regarding the risks of driving tall buses in strong side winds *(RO 2001:04 R1)*.

b) The Swedish National Road Administration is further recommended to seek the production of suitable aids for use by bus drivers to establish e.g. the highest permissible speed and the most suitable distribution of load in the bus with respect to prevailing road conditions and wind strengths *(RO 2001:04 R2)*.

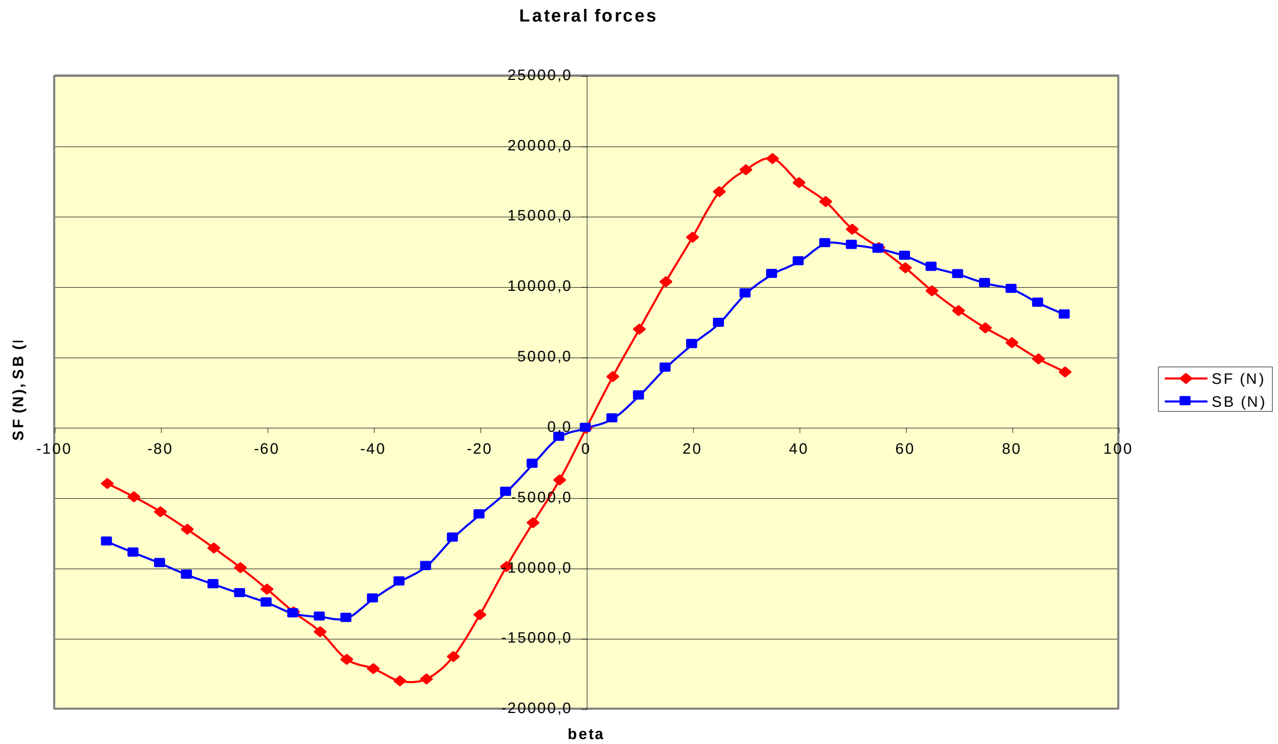
c) The Swedish National Road Administration and the Swedish Rescue Services Agency are recommended to seek safe solutions for rapid emergency evacuation of buses regarding both the possibilities of making one's way out of the bus and the knowledge and ability of the municipal rescue services regarding how to open evacuation routes from outside *(RO 2001:04 R3)*.

d) The Swedish National Road Administration is recommended to take steps in consultation with the Swedish Rescue Services Agency to ensure that the engine compartment of a bus is efficiently screened against the spread of fire to the passenger compartments *(RO2002:04 R4)*.

Run 1. Bus speed = 54 km/h (15 m/s). Wind speed = 25 m/s



Run 1. Bus speed = 54 km/h (15 m/s). Wind speed = 25 m/s



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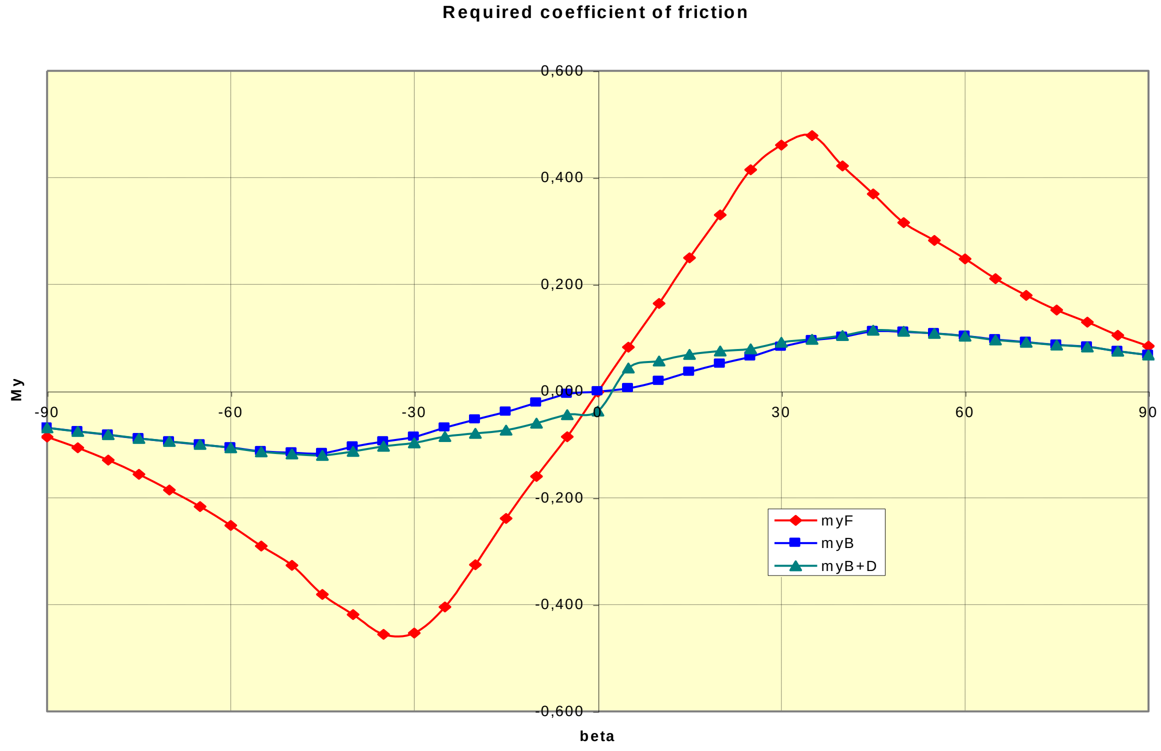
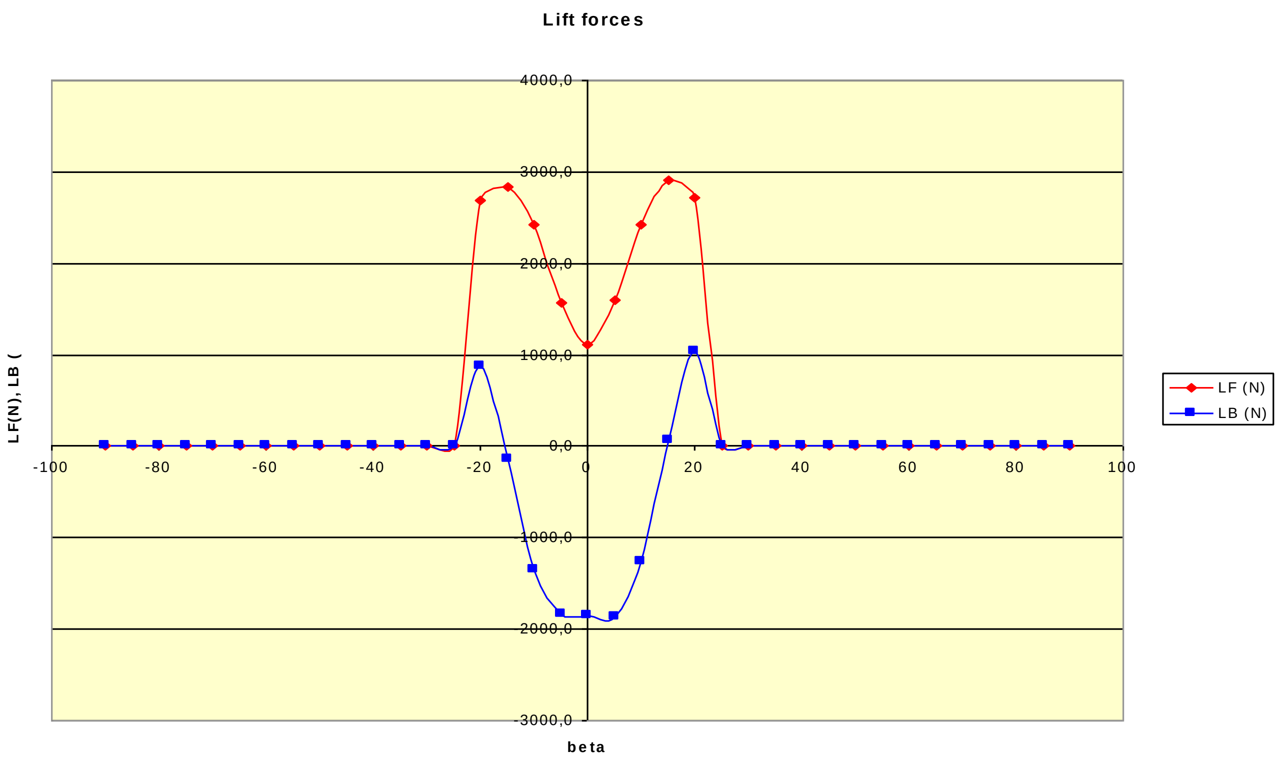


Run 2. Bus speed = 90 km/h (25 m/s). Wind speed = 10 m/s



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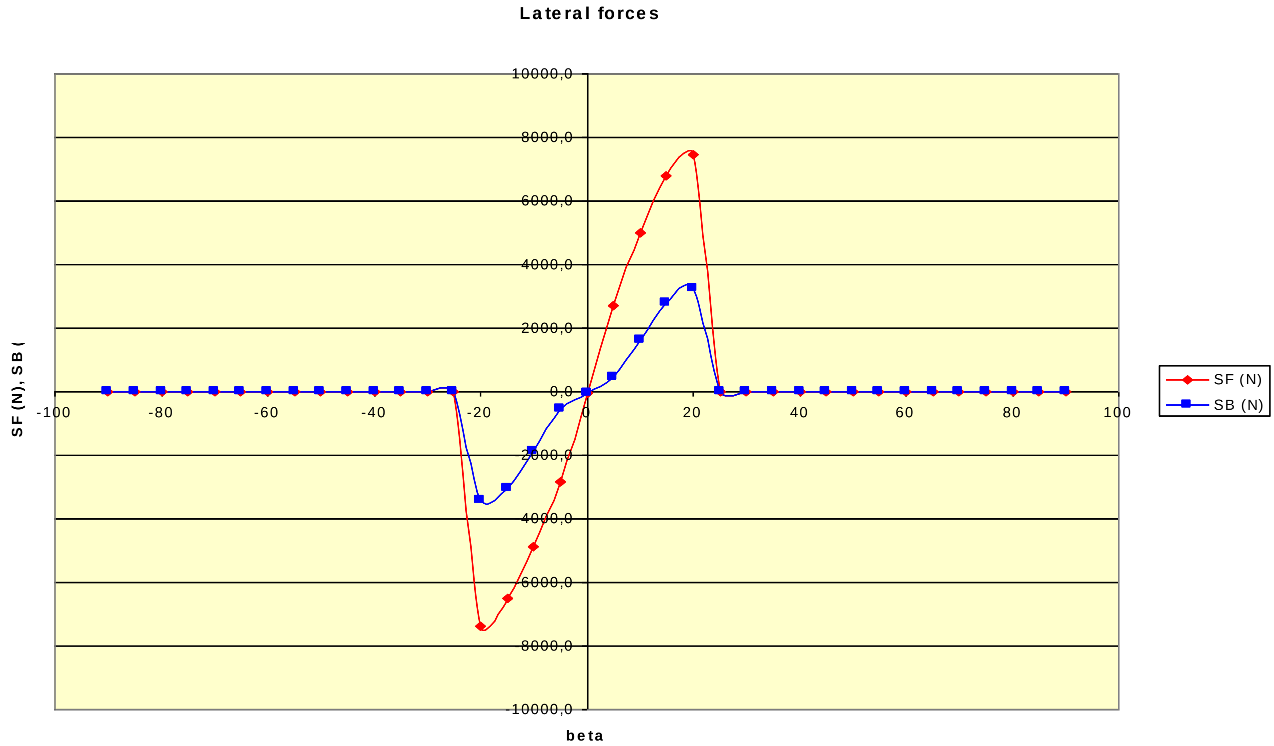
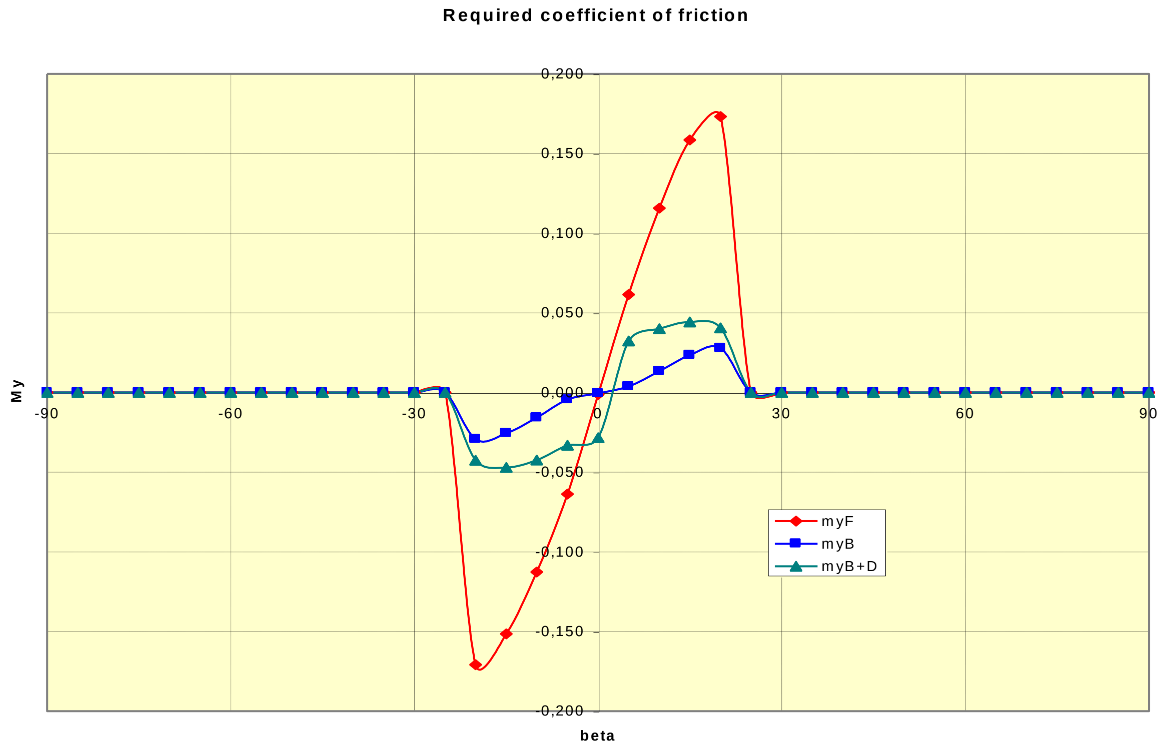
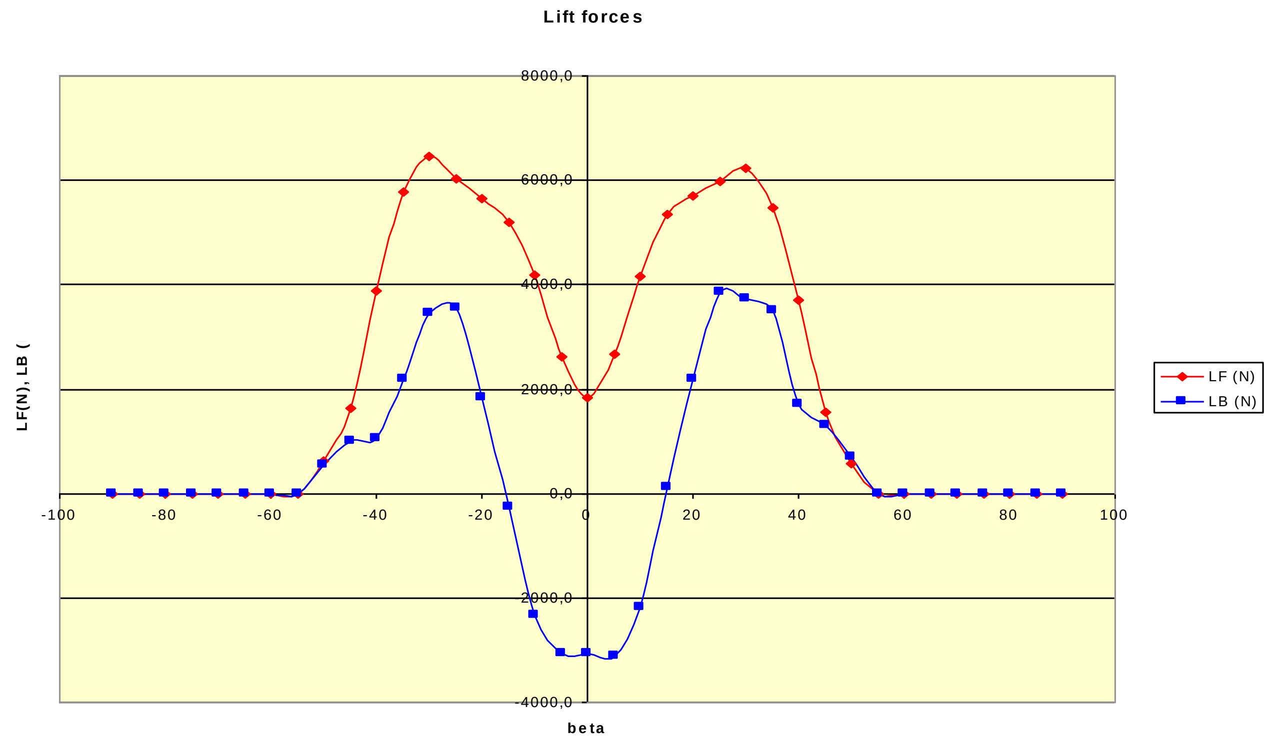


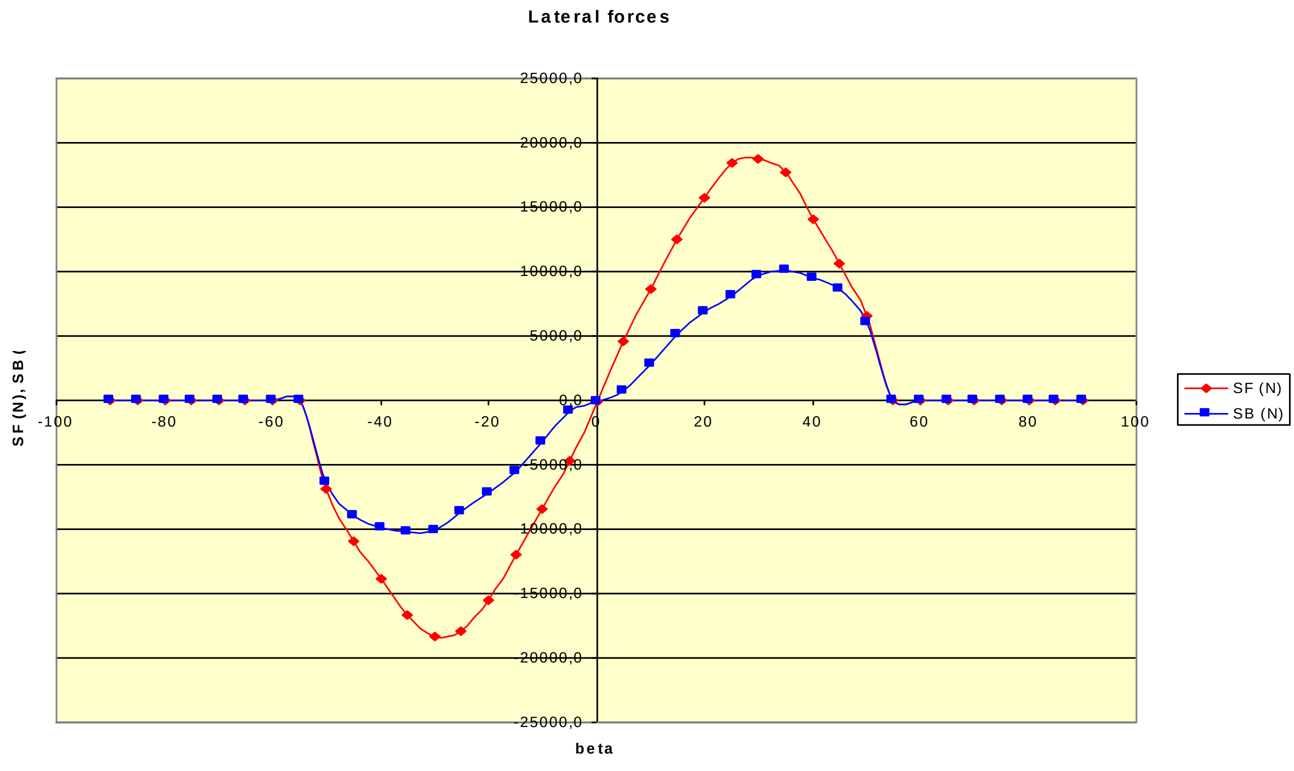
Run 2. Bus speed = 90 km/h (25 m/s). Wind speed = 10 m/s



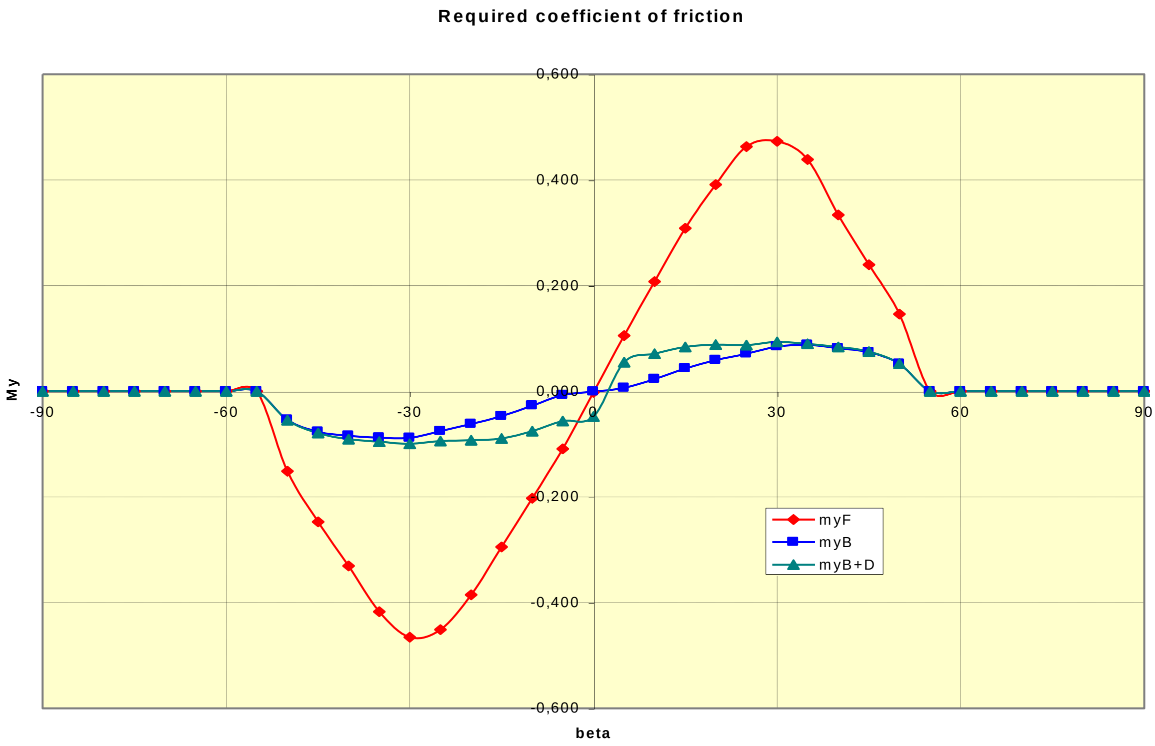
Run 3. Bus speed = 90 km/h (25 m/s). Wind speed = 20 m/s



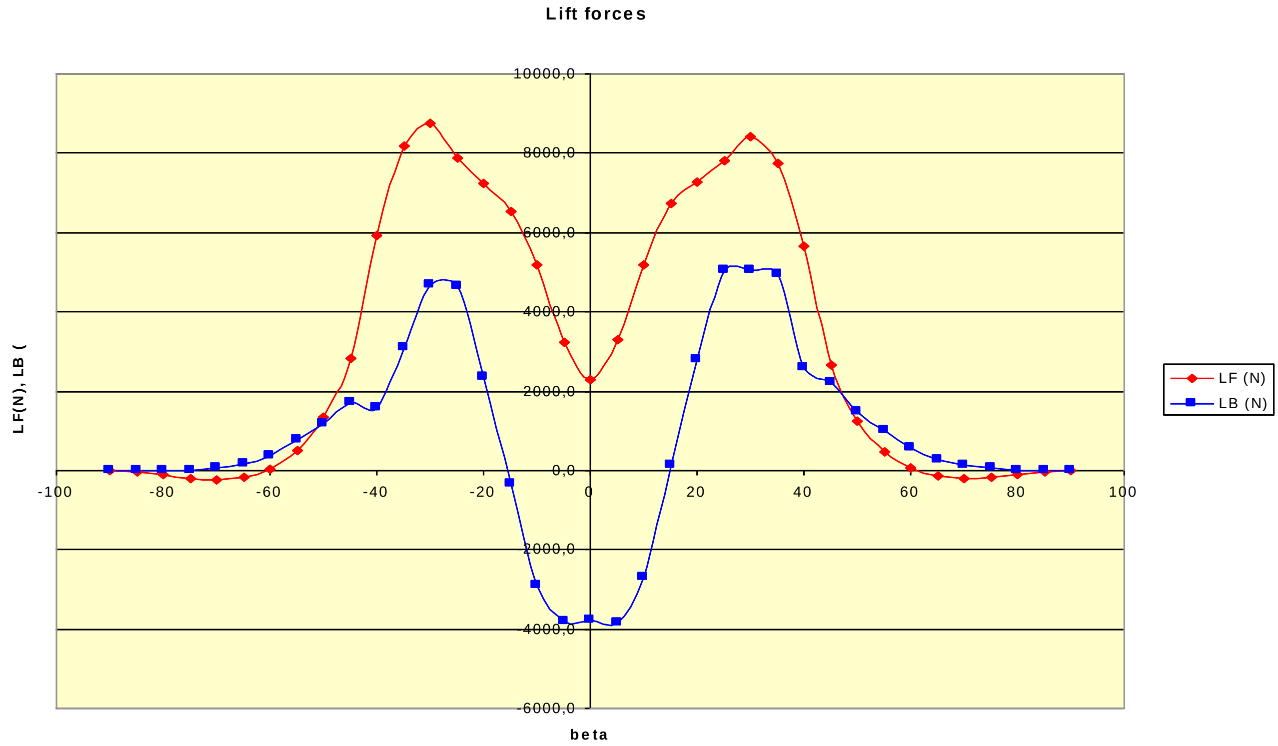
Run 3. Bus speed = 90 km/h (25 m/s). Wind speed = 20 m/s



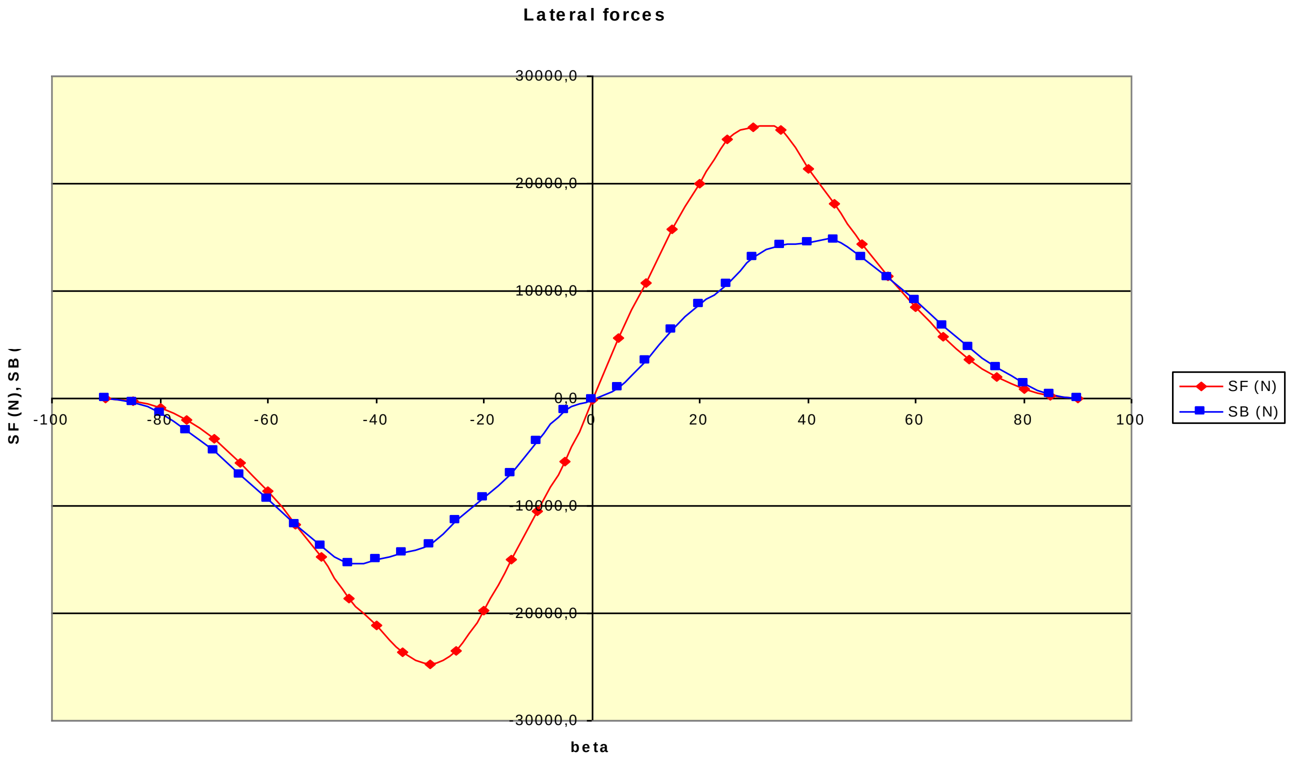
Run 3. Bus speed = 90 km/h (25 m/s). Wind speed = 20 m/s



Run 4. Bus speed = 90 km/h (25 m/s). Wind speed = 25 m/s



Run 4. Bus speed = 90 km/h (25 m/s). Wind speed = 25 m/s



Run 4. Bus speed = 90 km/h (25 m/s). Wind speed = 25 m/s