Vehicle Rollover Group

REPORT OF THE REVIEW OF INCIDENTS INVOLVING THE ROLLOVER OF AERODROME RESCUE AND FIRE FIGHTING VEHICLES

Graeme Day – BAA
Owen Healey – Civil Aviation Authority
Bill Kitchen – Airport Fire Officers Association
Simon Webb – Civil Aviation Authority

January 2011

CONTENTS

1 INTRODUCTION AND BACKGROUND

1.1 Aircraft rescue and fire fighting service (RFFS) vehicles are high-performance vehicles designed to get to an aircraft crash site within minutes and contribute to saving the lives of passengers and crews. The number of rollover incidents of RFFS vehicles in the last few years has caused concern to the industry and the regulator. It was decided to form a cross-industry group to review the vehicle rollover incidents and identify areas for improvement. This must be done to protect the occupants and enable these vehicles to safely perform the critical missions of aircraft rescue and firefighting for which they were designed and intended.

1.2 Thirteen UK RFFS vehicle rollovers have been documented since 1990. This is a large number of incidents considering the few miles and operational hours that the RFFS use these vehicles each year. What is even more puzzling is the fact that most of these incidents have occurred in non-emergency situations. Most of the documented cases occurred in training, practice, or other non-emergency situations.

1.3 Because of the serious nature of the RFFS response and the potential for the loss of life or serious injury to the operators of these vehicles as well as the safety of the flying public, this issue needed to be investigated. Should rollover situations occur under emergency response situations, it could put the flying public at risk. Though few of these incidents have occurred in actual response situations, the speeds necessary to maintain recommended response requirements dictate there must be confidence in the rescue vehicle and the competence of the drivers.

1.4 The typical airport response includes acceleration, possible high-speed driving, heavy braking, and the need to perform several 90-degree or greater turns. The RFFS respond under emergency situations at airports, thus requiring that the rescue vehicles have rapid acceleration. They must be able to brake under high-weight loads with transferring inertia conditions. Rescue vehicles must be responsive to large centre of gravity shifts under the high-speed turning radius at intersections of taxiways and runways at modern airports. These vehicles may be expected to operate in adverse terrain and on the public highway. Performance testing of all rescue vehicles should include those tests which emulate these types of response requirements.

1.5 In general, as jet travel developed, aircraft grew in size, length, and capacity, leading to the need for longer runways and taxiways. The need to respond to emergencies in minutes on these longer runways has required either the provision of new fire stations placed strategically or the development of faster responding rescue vehicles. Larger capacity aircraft also have very large fuel tanks. Certain wide-body aircraft, such as the Boeing 747-400, carry greater than 225,000 litres of fuel for long-range applications. Therefore, there is a great potential for large post-crash fuel fires. To meet this potential emergency, heavy rescue vehicles have steadily increased in size and complexity. Airports with runways of over 3,500 metres in length are not uncommon. The need to carry large amounts of water and extinguishing agents to deal with these post crash fuel fires has resulted in vehicles with critically high centres of gravity routinely reaching speeds in excess of 65 mph.

1.6 Many of the drivers involved in rollover incidents reported that the vehicles were travelling at relatively low speeds when the incidents occurred. Eyewitnesses and reconstruction have validated this in some cases. Yet in some incidents, drivers have not been found faultless.

Terms of Reference of the Vehicle Rollover[1] Group

1.7 In association with the Airport Operators Association (AOA) and the Airport Fire Officers Association (AFOA) the main purpose of the group is to evaluate the factors associated with appliance rollovers and recommend any Safety Initiatives and Safety Performance

[1] ‘Rollover’ is defined as an incident in which a motor vehicle overturns.

Indicators. The findings and recommendations will be shared with the AOA and Industry[2].

Key Tasks of the Vehicle Rollover Group

1.8 Perform a literature review of work already completed or underway in this area, both in the UK, Europe and internationally.

1.9 Engage with those who have experience of dealing with rollovers such as aerodrome RFFS, HSE and vehicle manufacturers.

1.10 Undertake a systematic analysis of risks relating to rollovers.

1.11 Review associated training issues.

1.12 Develop a strategy to mitigate against rollovers.

1.13 Identify options and recommendations to mitigate the risk of a vehicle rollover.

2 SCOPE AND WORKING

2.1 The Terms of Reference and Key Tasks of the Vehicle Rollover Group (VRG) are set out in the introduction to this report. The VRG were aware from the beginning that there has been previous work on the subject of vehicle rollovers and the issues that arise from them. The group were conscious not to cover old ground and wanted to produce a report that would result in improvements to the safe response of RFFS vehicles.

2.2 It was therefore decided that the report would not reproduce existing research or reports but would reference them. It would take the lessons learned and good practice developed from those lessons to produce an action plan to deal with any gaps.

2.3 The research around rollovers and engagement with those who are involved in vehicle design, manufacture and use was carried out to confirm the known issues that lead to a rollover. It was soon identified that the main factors revolved around the design of the vehicles in terms of their centre of mass and the driving of the vehicles. As the main contributor to a vehicle's weight is the amount of water and foam carried, a section of the report looks at the future effectiveness of foams and the impact on the gross vehicle weight.

2.4 The training issues around driving are mixed with a much wider review of large goods vehicle and emergency response driving. The group has sought to gain from these reviews and look at the potential to build on them.

2.5 The resulting strategy to achieve the goal of reduced vehicle rollovers is reflected in the action plan with the two main aims:

- To ensure a vehicle is as stable as possible;
- To ensure drivers are competent.

2.6 Rather than produce a report with a number of options and recommendations it was decided to focus on an action plan and ensure that the resulting work dealt with the key issues that were already identified in previous work.

[2] 'Industry' for this document includes the RFFS, vehicle and equipment suppliers, regulators and aerodrome operators.

3 INCIDENTS

Introduction

3.1 The initial purpose of collecting this data was to understand what similarities there might be with vehicle rollover incidents and subsequently provide additional work streams that could be looked into as possible causation of vehicle rollovers. The information provided by airports at times has been sketchy, as some of these incidents occurred long in the past and relevant information has not been available or kept on file for reference purposes.

Overview of Incidents

3.2 The table below shows all the incidents that have been reported and to which we have had access. The second table provides information on the incidents covering the main areas of vehicle operation at the time, the probable speed, weather conditions and the possible cause of the incident.

3.3 The results show that there have been 13 UK incidents since 1990. Many incidents have occurred in other countries; however information on incidents abroad generally seems harder to come across. It is not known if this is due to fewer incidents or that this information is not publicly shared.

3.4 Vehicle Rollover Incidents (as at July 2010)

Date	**Vehicle Type**	**Location**	**Weather Conditions**	**Number of Crew**	**Injuries Sustained**
Not Known	Jetranger	Runway, Southampton	Dry	3	Not known
1985	Jetranger	Off airport incident, Donnington	Not known	3	1 x head injury (not serious)
1990/91	Javelin	Link Echo, Glasgow	Below Zero	1	Cuts/Bruises
Early 1990’s	Unipower	Taxiway, DI Run, HIAL	Hail	Not Known	Not Known
Early 1990’s	Protector	Single track Lane, HIAL	Not known	Not known	Not known
Summer 1999	Nubian Major	Driver training Area, Plymouth	Not Known	2	No Injuries
Jan 2000	Protector	HIAL	Recent Rain/Frost	3	1 x back Injury
4 April 2004	Not Known	Timed response, Main runway, Isle of Man	Not known	1	No injuries
13 May 2004	Not Known	Routine training exercise, end of taxiway, Jersey Airport	Not known	3	3 taken to hospital nothing serious
April 2007	Cobra 2	Timed response, Taxiway, Robin Hood Airport	Dry, light wind	4	Cut head, all 4 sent to hospital, discharged

7 December 2007	Reynolds Boughton RB44	Runway crossing, Kemble Airport	Dry	3	3 X bruising, 1 X back injury, 1 X BCF inhalation
Aug 2009	Cobra 2	Outside Station, Farnborough	Not Known	3	Not Known
April 2010		Redhill Aerodrome (Awaiting Report)	?	?	?

3.5 Some of the incident reports and data have been limited; therefore we have had to estimate the speed the vehicles were likely to have been travelling at the time. This has been done by reviewing the information provided and using our vehicle experience.

3.6 In the past it has been common to find that the incidents tend to be put down to driver error. However evidence suggests that this is not always the case.

3.7 The table shows that there are far more possible causes to these incidents and they may have occurred due to other factors prevalent at the time. These can now act as a guide to areas of concern that still need to be addressed.

3.8 Factors

Speed	**Operation**	**Possible Cause***
Slow x 6	Response time turnout x 2	Driver error x 10
Medium to slow x 3	Emergency Response x 1	Vehicle failure x 1
High x 0	Driver Training x 4	Other x 7
Unknown x 4	Daily Inspection Run x 2	
	Unknown x 4	

*There may be more than one possible cause.

Conclusions on Incidents

3.9 Since 1990 there have been 13 vehicle rollovers in the UK for which we have details. This equates to one fire vehicle rollover approximately every 18 months. There are approximately 257 major fire appliances operating within the United Kingdom at UK Licensed Aerodromes. The number of instances reported are very few in comparison. However, over the last 20 years it would appear that these rollovers are occurring more frequently.

3.10 Whilst carrying out our investigation of these incidents there is a belief amongst some Fire Officers that one of the issues with vehicles rolling over may occur where vehicles change gear whilst cornering which provides enough inertia at that critical point to roll the vehicle over.

3.11 Along with this report, work has been undertaken to look at the sloshing of water within the vehicle tanks. This in itself could be enough to cause a vehicle to roll however, with the addition of inertia from a gear change included, it would be prudent to try and investigate this possibility further.

Recommendations

Recommendation 1

A database should be created for vehicle rollovers starting with this report and additional information provided to ensure that this information is being captured and recorded.

Recommendation 2

Should an airport have an incident there should be a requirement to provide relevant information that appears to be missing from most of the reports, i.e. weather conditions, what the vehicle was being used for, speed at the time of the incident, additional factors, witness statements, time and date, drivers experience and any additional information.

4 DRIVING

Introduction

4.1 This section looks at the influence that existing aviation and regulatory requirements have on emergency response driving. An emergency response may include a route both on the aerodrome and the public highway with each attracting its own specific requirements in terms of driving requirements and competence.

4.2 The subject of new Driving Standards for a response on the public highway is still under consideration by the Department for Transport (DfT) and the Department for Communities and Local Government (DCLG) to decide their action. They will be considering drafting the new regulations in the near future. On 24 April 2008 the Chief Fire Officers Association (CFOA) advised its members to seek an agreement with airports under Section 15 and 16 of the Fire and Rescue Services Act 2004 on their response outside the airport boundary.

Aerodrome Response Objective

4.3 The International Civil Aviation Organisation (ICAO) sets out standards and recommended practices (SARPs) for international aviation. These SARPs are adopted by the UK and set out in the Civil Aviation Publication (CAP) 168 – Licensing of Aerodromes. They include numbers of RFFS vehicles and objective response times for those vehicles to attend an aircraft accident and commence fire fighting.

4.4 As part of the oversight arrangements at aerodromes the CAA will expect the response objective to be demonstrated and recorded. This time objective places pressure on all parts of the response system, and in particular the drivers.

National Highway "High Speed" Standards

4.5 The development of the new standards is in response to the Road Safety Act 2006, which introduces significant changes to the Road Traffic Regulations Act 1984. In essence, these changes mean that only drivers who have satisfactorily completed a course of training in driving vehicles at high speed will be exempt from posted speed limits when the vehicle is being used for "fire and rescue authority purposes…or for ambulance or for police or Serious Organised Crime purposes." It also supports regulations so that only those driver trainers who have completed the necessary course will be able to deliver driver training at this level.

4.6 For the purposes of the new standards, 'driving at high speed' is defined as follows: "a driver, from an emergency service, is driving at high speed when he or she legally decides to use the exemption and exceed the speed limit, on any stretch of road, so as to enable them to arrive at an incident or carry out other activities of the service where the higher speed was necessary" such as:

- attending an emergency call;
- investigating, preventing or stopping the commission of a crime;
- helping a member of the public who is in urgent need of emergency assistance.

High speed should be construed as any speed which exceeds that of any statutory speed limit in force on the road at that time. It might also be interpreted as a speed which is below the statutory speed limit, but in excess of a speed which would be appropriate to the prevailing road conditions at the time.

Regulation 3 of the Road Vehicles Lighting Regulations 1989 (Interpretation) clarifies the term 'emergency vehicle':

"A motor vehicle of any of the following descriptions:

(a) a vehicle used for fire brigade, ambulance or police purposes;"

4.7 Whilst emergency vehicles are responding to an emergency call and the use to which the vehicle is being put is hindered, they are exempt from some motoring regulations; however, they are not exempt from the offence of Section 3 Road Traffic Act 1988, careless or inconsiderate driving.

Current Situation

4.8 The principal role of the RFFS is to provide an immediate intervention at aircraft accidents to save lives by creating survivable conditions within the aircraft fuselage. To achieve this aim and to comply with CAP 168 requirements firefighters may have to drive at high speed. At some locations, the Airport Fire Service delivers a domestic response to areas outside of the airside boundary which may involve high speed driving on the public roads.

4.9 The Road Traffic Regulations Act 1984 Section 87 (as will be amended by S 19 of the Road Safety Act 2006) deals with the exemption from posted speed limits. The proposed amendment is:

> "(1) No statutory provision imposing a speed limit shall apply to any vehicle on an occasion when –
>
> (a) it is being used for fire and rescue authority purposes of for or in connection with the exercise of any function of a relevant authority as defined in Section 6 of the Fire (Scotland) Act 2005, for ambulance purposes or for Police or Serious Organised Crime Agency purposes.
>
> (b) it is being used for other prescribed purposes in such circumstances as may be prescribed."

4.10 The issue with the above relaxation is that the vehicle must be used for fire and rescue authority purposes and as such, does not apply to the aerodrome RFFS. However, as detailed in (b) above, aerodrome RFFS vehicles could take advantage of the relaxation if they were prescribed by regulation.

There are two alternatives:

a) Any supporting service to enter into a mutual aid agreement with a prescribed service allowing it to be used for their purposes.

b) Accepting that all fire services both on and off the airport premises are under the responsibility of the " fire and rescue authority" and attendance by services is under the control of the local authority and therefore for their purpose. This approach could be viewed as carrying too much risk as it could be tested in law.

As a result of this a agreement under Section 15 and 16 of the Fire and Rescue Services Act 2004 needs to be in place at all RFFS locations in the UK.

4.11 Other CAP's covering this subject include CAP 699, CAP 642 Airside Safety Management Chapter 4 and CAP 700 Operational Safety Competencies.

4.12 As Category 2 responders under the Civil Contingencies Act 2004, RFFS staff would also be required to attend incidents off airport. Part 1 Sections (2)(i)), S(4), S(5), and S(7) detail the requirements that would be placed on a Category 2 responder.

4.13 At present, under the terms and conditions of MoUs (where they are in place), RFFS staff respond off airport to a variety of incidents.

Human Factors

4.14 There can be no doubt that human factors are a large and significant factor in vehicle accidents. These factors can be broken into imposed and self-imposed pressures. At all stages of the response system of work the influence of these pressures must be considered and reduced. Whether it is the professional pride of the driver, the influence of the supervisor/instructor or peer pressure of the crew it must be factored into the response and the training of the driver and other personnel.

Driver Competence

4.15 At present, responsibility for setting standards and training drivers to ensure their competence lies with their employer. When the regulations under the Road Safety Act 2006 are enacted there will be common standards for the competence of emergency response drivers who need to exceed the speed limit on the public highway. The standards will not include occupational needs, role and the type of driving being undertaken. These aspects will need to be added to the basic high speed training to complete the health and safety needs of each organisation.

4.16 Any driver must be competent in their role. There will be a process that will be followed to identify the response requirements, the topographical features of the response area, the types and nature of the response vehicle that will inform the competence requirements of the driver. Those requirements can then be met in a number of ways, however the end result must be to a set standard and be monitored and assured.

In summary the following must be in place:

- An assessment of the use of the vehicle;
- An assessment of the topography where it will be used;
- A suitable vehicle, fit for purpose;
- Policies and procedures to define and implement standards;
- Competence standards to match the above;
- Suitable routes to competence, such as training or accreditation of prior learning;
- Assessment of competence;
- Maintenance of competence;
- Monitoring and review.

Driver Certificate of Professional Competence

4.17 The Driver Certificate of Professional Competence (Driver CPC) is a new qualification for professional bus, coach and lorry drivers. It has been introduced across Europe with the aim of improving road safety and helping to maintain high standards of driving.

4.18 Depending on when a driver gained his/her vocational licence, he/she will get their Driver CPC either through having 'acquired rights', or by passing initial qualification tests. The initial qualification tests can be taken at the same time as vocational driving tests.

4.19 Driver CPC is valid for five years. New drivers who have qualified via the initial qualification route will receive a Driver Qualification Card (DQC), which they can show as proof that they hold Driver CPC. Existing drivers will receive their DQC when they have completed their 35 hours of periodic training.

4.20 The Driver CPC aims to improve road safety by helping drivers of buses, coaches and lorries maintain and develop the skills and knowledge they need. It covers subjects such as knowing how to load a vehicle safely, and how to comply with relevant rules and regulations such as drivers' hours.

Exemptions from Driver CPC requirements

4.21 You will not need a Driver Certificate of Professional Competence (Driver CPC) if the vehicle you drive:

- has a maximum authorised speed not exceeding 45 kilometres per hour;
- is used by, or under the control of, the armed forces, civil defence, the fire service and forces responsible for maintaining public order;
- is undergoing road tests for technical development, repair or maintenance purposes, or is a new or rebuilt vehicles which have not yet been put into service;
- is used in states of emergency or assigned to rescue missions;
- is used in the course of driving lessons for any person wishing to obtain a driving licence or a Driver CPC;
- is used for non-commercial carriage of passengers or goods or for personal use;
- is carrying material or equipment to be used by the driver in the course of his or her work, provided that driving the vehicle is not the driver's principal activity.

Training of Drivers

4.22 Currently there are standards for driving emergency vehicles on the public highway set down by a number of bodies and organisations. Generally they consist of roadcraft, a theoretical test, attitude training and a response assessment. Some organisations use internal providers and some contract out all or part of the elements.

4.23 At present an emergency service working group has developed student and instructor competencies, occupational standards and quality assurance measures. These will be finalised by the Department for Transport, circulated for consultation and then issued as Codes of Practice.

4.24 Qualifications for drivers are likely to be developed that will be aligned to NOS Ff 19 to take account of the fact that there will be no “Grandfather rights” under the new legislation and that drivers will need to be able to demonstrate their competence.

4.25 Driver training will be competency based and will need to be provided by high speed driving instructors.

4.26 The DfT’s position regarding this is clear i.e. if a person has not received high speed driver training then that person cannot drive at speed on the public highway.

4.27 The new regulations are proceeding but no implementation date has been set.

Conclusion on Driving

4.28 The development of new driving standards for emergency response on the public highway is in response to the Road Safety Act 2006, which introduces significant changes to the Road Traffic Regulations Act 1984. In essence, these changes mean that only drivers who have satisfactorily completed a course of training in driving vehicles at high speed will be exempt from posted speed limits on the public highway. As a result of the new standards, Airport Fire Managers will need to consider the following:

- All RFFS personnel who are required to drive at speed must receive high speed driver training. Existing Emergency Fire Appliance Driving (EFAD) or suitable alternatives, will almost certainly cover most people and satisfy the Code of Practice[3];

- High speed driver training must be provided by high speed driver instructors who have demonstrated their competence as per the high speed driving instructor Code of Practice (when published);

- Fire Service Managers will need to ensure that all drivers have received an EFAD course or suitable alternative within the 5 year period prior to implementation

- Until such time as the RFFS is recognised as a prescribed user under the Road Traffic Regulation Act 1984 Section 87 (as amended by S 19 of the Road Safety Act 2006), AFMs will need to ensure that an MoU exists between their location and their local authority Fire and Rescue Service to cover the possibility of a response off airfield where they need to exceed the speed limit;

- Driver CPC is now in force and may need to be considered;

- Airport manoeuvring areas are not covered by the new high speed training requirements, however aerodrome by-laws may stipulate road safety conditions in these areas. The Health and Safety Executive may well use the content of by-laws and Codes of Practice in any injury enquiry into the management of operations etc.;

- Airport roads may be covered by the S87 RTRA 1984, which is the amended legislation.

Recommendation 3

An Aerodrome Vehicle Training Guide should be developed which takes into account relevant driving regulations, Driver Certificate of Professional Competence requirements and advice from the CFOA Emergency Response Driving Group.

4.29 References

a) Motor Vehicles (Wearing of Seatbelts) Regulations 1993
b) Road Traffic Act 1988
c) Road Traffic Offenders Act 1988
d) Council Directive 2003/20/EC – Office of Public Sector Information
e) RoSPA Managing Occupational Road Risk
f) RR018 HSE Management of Work Related Road Safety
g) INDG382 HSE Driving at Work: Managing Work Related Road Safety
h) CAP 168
i) CAP 700 Operational Safety Management
j) CAP 642 Airside Safety Management
k) Road Traffic Regulations Act 1984
l) Civil Contingencies Act 2004
m) Road Safety Act 2006
n) Fire and Rescue Services Act 2004
o) Air Navigation Order, Rules of the Air – Rights of Way on the Ground
p) Health and Safety at Work Act 1974
q) Driving Standards Agency - www.dsa.gov.uk

[3] The standards bought in by the Road Safety Act are intended to be set out in a Code of Practice.

5 VEHICLES

Introduction

5.1 This section of the report looks at the influence that vehicle standards have on the stability of RFFS vehicles.

5.2 The requirements for vehicles are set out at various levels and in various standards. At the highest level the ICAO Airport Services Manual sets out guidance. At the next level there are international standards that go into more detail. Lastly there are national standards that can be prescriptive as they deal with one country's legal requirements surrounding vehicles, their design, construction and use.

5.3 The danger with a number of requirements or guidance is that there can be an overlap of requirements or worse gaps between requirements. Those gaps could be critical and provide the hole in the "Swiss cheese" accident model.

5.4 This report looks at those standards and identifies where the gaps are. It also identifies work that may be necessary to fill those gaps.

Gaps

5.6 The simplistic overview of vehicle rollovers is that they will be caused by the shifting of the Centre of Mass (CoM), also known as the Centre of Gravity (CoG). Therefore the key prevention measure is to design or operate vehicles to avoid the possibility of the CoM shifting to the point of rollover.

5.7 All the standards reviewed include measures to reduce the potential for a rollover; some are preventative, such as design measures, and some are protective, such as lean warning devices. So the key to the prevention of rollovers is to include in a vehicle specification a range of measures that together prevent a rollover. The other key measure to be taken is to ensure that the driving of the vehicle does not cause a rollover. The issue of driving is dealt with in section 4 of this report; however, aids such as lean monitors will be mentioned in this section as protective options.

5.8 There are gaps in some areas that impinge upon the CoM and its movement in an RFFS vehicle. These concern the suspension systems and fluid movement.

5.9 The Federal Aviation Administration (FAA) of the USA conducted tests[4] with Vehicle Suspension Enhancement Systems that highlighted the problems with suspension systems and proposed a retrofit to restrict the roll of RFFS vehicles. Since that time the design of suspension systems has advanced and the roll of vehicles has been controlled on new vehicles; however, it would still need to be focused on in any procurement specification. Also warning devices to alert drivers of potential unsafe lean angles are available and should be considered for all new vehicles. A key point to be remembered regarding lean angles and suspension is that there will be differences between the static and dynamic performance. A tilt test is an indicator but not the whole position regarding lean of vehicles and as with many aspects of the rollover problem there is not one solution but a number of options that together will reduce the risks.

5.10 The movement of fluid in tanks and its effect on the stability of transport systems is well researched, documented and indeed regulated in many areas such as ships. The implications of sloshing fluids are dealt with in section 6 of this report looking at media. However, it needs to be mentioned here that a means of controlling sloshing is by the use of baffles within tanks and the shape of the tank itself. All standards cover baffles in tanks but in varying degrees and none with any reference to a background technical basis. Section 6 on media identifies the need for further work in this area.

---

[4] Federal Aviation Administration, Evaluation of Retrofit ARFF Vehicle Suspension Enhancement to Reduce Vehicle Rollovers, DOT/FAA/AR-02/14, March 2002 - http://www.airporttech.tc.faa.gov/Safety/Downloads/02-14_ARFF_Rollover.pdf

Standards of Design

5.11 As mentioned above there are a number of standards of varying detail and technical complexity. The key areas that most standards deal with are:

- The significant hazards
- General requirements
- Performance requirements
- Dimensions
- Chassis
- Vehicle body
- Engine
- Gearbox – manual, semi automatic, automatic
- Transmission
- Electrical equipment including lighting
- Suspension
- Tyres – type, condition, pressures, remoulds, cutting and derogations
- Brakes
- Steering
- Fire fighting systems
- Water tanks
- Foam system
- Monitors and nozzles
- Booms and High Reach Extendable Turrets (HRETS)
- Complementary agent systems
- Control systems and warning devices
- Noise
- Mechanical coupling
- Breakdown and towing
- Acceptance tests including tilt tests
- Enhanced vision systems

5.12 In the majority of the areas above there will be safety critical features of the design that users, procurers, manufacturers and regulators will consider essential in any standard. The problem with any standard is any gaps between specifications. This leaves those writing a specification for a new vehicle with the job of picking the essential and necessary elements from a number of standards. The advantage of this approach is that gaps are unlikely to occur.

5.13 The following is an outline of the relevant standards:

Body	**Standard**	**Comment**
ICAO	Airport Services Manual, Part 1 – Rescue and Fire Fighting, Chapter 5 – Factors in the Specification Process for Rescue and Fire Fighting Vehicles.	This sets out considerations and factors to be considered in the specification of RFFS vehicles. It is not a prescriptive standard but provides an outline template for a specification.
CAA	CAP 168, Licensing of Aerodromes, Chapter 8 – Rescue and Fire Fighting Service, Section 11 – Appliances.	This section refers to the guidance given in the ICAO manual above. Previous versions of CAP 168 have covered vehicles in more detail, however much of it

		was a duplication of the guidance in the ICAO manual.
NFPA	NFPA 414 – Standard for Aircraft Rescue and Fire-Fighting Vehicles (2007 Edition).	This standard is a very detailed and prescriptive document drawn up from a cross-section of interests. It has a high relevance to the USA as it is used by the FAA in its funding process of RFFS vehicles. As such it is very detailed. It can be useful as a reference for various technical aspects of vehicle design and testing.
European Standard	BS EN 1846 - Firefighting and rescue service vehicles, in three parts: Part 1 - Nomenclature and designation Part 2 - Common requirements - Safety and performance Part 3 - Permanently installed equipment - Safety and performance	The standard focuses on safety and performance and is not specific to airport vehicles. It is a useful tool in developing a specification.
National Commision for airport safety equipments, Ministry of the Interior, France	Technical Specification 004/2005 – ARFFS fire fighting vehicles Common technical specifications.	This is a comprehensive standard for airport vehicles which builds on the ICAO guidance and references other EN standards where appropriate. It has good guidance for purchasers of vehicles and provides the majority of the safety critical guidance in one standard.
The Society of Automotive Engineers (SAE)	Ref. SAE J2180 – A Tilt Table Procedure for Measuring the Static Rollover Threshold for Heavy Trucks.	This is considered good practice and should be referred to in any specification or tender. The vehicle should be loaded to its normal carrying load.

Pre-owned Vehicles

5.14 Vehicles are often sold off and used at other aerodromes, re-furbished or re-fitted with different equipment. In each case the effect on the vehicle must be considered and the effect on its stability re-assessed in the same way that it is for a new vehicle.

UK CAA Position

5.15 In past versions of CAP 168, in Chapter 8, there have been vehicle specifications. The decision was taken at the 2008 review to remove the standards as the areas that were covered were dealt with in other documents.

5.16 There is good high-level guidance in the ICAO Airport Services Manual and more detail in the technical standards. The key to a comprehensive specification is not that a vehicle has all the features, but that all the critical features have been considered.

Conclusion on Vehicles

5.17 Any vehicle is a complex mix of design features that come together to produce a comprehensive piece of equipment to perform a variety of functions. Most times well-designed vehicles are fit for purpose and perform effectively. However, there are occasions where a vehicle or a model has gaps in its performance. To avoid these gaps you can either buy a tried and tested model or ensure that its design is well thought through and its manufacture is to a quality controlled standard.

5.18 There can be problems where either a purchaser alters or adds to a basic design to the point where it moves outside its design parameters. There is, therefore, a strong case for procuring vehicles to common standards. If we wish to recommend a standard, the question is, which standard? We can either recommend one that deals with most of the safety critical areas in the list above or perhaps construct our own standard. To do so would take a large amount of resources, time and money.

5.19 Vehicles are being procured all the time and manufacturers are tendering against specifications. If the manufacturers believe that there is a problem and would like to develop either a new standard or a procurement guide for RFFS vehicles, they should consider the needs of the customer and the experience from previous procurement processes.

5.20 A solution could be to pick up on the point above and produce a list of considerations for procurement matched to appropriate standards. This would be an easier task and could provide a good benchmark guide building on the high level ICAO Airport Services Manual. Part 1, Chapter 5 'Factors in the Specification Process for Rescue and Fire Fighting Vehicles'. If this guidance is used as the basis with added references to standards this could be useful to those constructing a specification.

Recommendation 4

The current vehicle standards should be bench-marked and cross-referenced to the guidance in the ICAO Airport Services Manual, Part 1, Chapter 5, to provide safety-critical[5] considerations for RFFS vehicle specifications.

5.22 References:

a) Federal Aviation Administration, Evaluation of Retrofit ARFF Vehicle Suspension Enhancement to Reduce Vehicle Rollovers, DOT/FAA/AR-02/14, March 2002 - http://www.airporttech.tc.faa.gov/Safety/Downloads/02-14_ARFF_Rollover.pdf

b) ICAO Airport Services Manual, Part 1, Rescue and Fire Fighting, Doc 9137-AN/898, Third Edition, 1990

c) Civil Aviation Authority, Civil Aviation Publication CAP 168, Licensing of Aerodromes, Chapter 8, Rescue and Fire Fighting Service (RFFS), December 2008 http://www.caa.co.uk/docs/33/CAP168.PDF

d) National Fire Protection Association, NFPA 414: Standard for Aircraft Rescue and Fire-Fighting Vehicles, 2007 Edition http://www.nfpa.org/catalog/product.asp?pid=41407&order%5Fsrc=B484

e) BS EN 1846-1:1998, 1846-2:2009, 1846-3:2002. Fire Fighting and Rescue Service Vehicles. http://www.standardsuk.com/shop/products_list.php?cat=277&searchtype=category

[5] A safety-critical system is a system whose failure or malfunction may result in death or serious injury to people, or loss or severe damage to equipment or environmental harm.

f) National Commision for airport safety equipments, Ministry of the Interior, France. Technical Specification 004/2005 – ARFFS fire fighting vehicles Common technical specifications; http://www.stac.aviation-civile.gouv.fr/cnmsa/textes_cnmsa/gb/ARFFS_fire_fighting_veh.pdf
g) Society of Automotive Engineers, SAE J2180, A tilt Table Procedure for Measuring the Static Rollover Threshold for Heavy Trucks. http://standards.sae.org/j2180_199812/ .
h) Federal Emergency Management Agency, US Fire Administration, Safe Operation of Fire Tankers, December 2002, http://www.iaff.org/hs/EVSP/USFA%20Safe%20Operation%20of%20Fire%20Tankers.pdf
i) Central Scotland Fire and Rescue Service, Alloa Appliance RTC 23 January 2008, Presentation to CFOA Road Safety Conference 1 October 2010.
j) Federal Aviation Administration, Advisory Circular AC 150/5210-23, 30 September 2010, ARFF Vehicle and High Reach Extendable Turret (HRET) Operation, Training and Qualifications http://www.faa.gov/airports/resources/advisory_circulars/media/150-5210-20/150_5210_20_chg1.pdf

6 Media

Introduction

6.1 This section of the report focuses on the contribution made to RFFS vehicle stability by the fire fighting media carried, i.e. water and foam concentrate.

6.2 Two factors are involved; the first is the effect on the centre of gravity that carrying large amounts of liquid has on a vehicle. The second is the effect the vehicle movement has on the liquid; this is known as “sloshing”.

6.3 This report outlines the issues with both of the above and suggests future work to alleviate the effects that both can have on a vehicle’s stability.

Centre Of Gravity Or Centre Of Mass (Com)

6.4 The commonly known Centre of Gravity is actually the Centre of Mass[6] (CoM) and defined as follows:

“The centre of mass or mass centre is the mean location of all the mass in a system.”

6.5 It is relevant to any vehicle in that the higher the CoM the more likely the vehicle is to topple over when cornering unless the width is proportionally increased. The basic principle in vehicle design is, therefore, to keep the CoM as low as possible. In the case of fire appliances this has always caused problems as to get a liquid tank/s low means they interfere with drive and suspension systems and have to be constructed around the chassis. If tanks are positioned lower in the vehicle it may have an impact on the position and working of the pump as most rely on being gravity fed.

6.6 With an airport fire vehicle there is a large amount of liquid to be carried, therefore the chassis is substantial in order to take the weight and this affects the options for tanks. The result is that tanks generally sit on top of the chassis which means the CoM is high. One means of lowering the CoM is to widen the wheelbase of the vehicle; however, this can give access problems especially if a response is planned outside the aerodrome on the public highway where there are limits on wheelbase size through vehicle construction regulations.

Centre of Mass in Standards

6.7 Standards generally deal with CoM by a combination of weight distribution between wheels and axles and tilt tests. The principle is to get an even distribution of the weight

[6] Encyclopædia Britannica. 2010. Encyclopædia Britannica Online. 17 Aug. 2010 <http://www.britannica.com/EBchecked/topic/102775/centre-of-mass>.

of a vehicle between all its wheels. A tilt test is then carried out to measure the static rollover threshold; very simply, it determines the angle at which the trucks could tip over. ICAO sets down the static tilt for vehicles at 30^{o} for vehicles up to 4,500 litres water capacity and 28^{o} for vehicles greater than 4,500 litres water capacity.

6.8 The USA standard NFPA 414 also sets out a test for cornering stability; however, it relies on the driver steering the vehicle in a circle until he judges a maximum safe speed is reached. This test could be considered too subjective, and indeed dangerous, to be seriously considered. Indeed it does call into question the whole basis of the standard as it does not appear to include a safety margin in the criteria.

6.9 The Society of Automotive Engineers (SAE) publishes a tilt table procedure for measuring the static rollover threshold for heavy trucks (Ref. SAE J2180). This is seen as good practice and should be referred to in any specification or tender.

6.10 The role of suspension systems in the rollover effect has been investigated and solutions have been developed and integrated into vehicles. The vehicle standards are dealt with in section 5 of this report.

Sloshing

6.11 Sloshing can be defined as follows:

"In fluid dynamics, slosh refers to the movement of liquid inside another object (which is, typically, also undergoing motion). Strictly speaking, the liquid must have a free surface to constitute a slosh dynamics problem, where the dynamics of the liquid can interact with the container to alter the system dynamics significantly."[7]

6.12 There have been many studies into sloshing, as many liquid carrying vehicles, whether fully or partially loaded, are known to be more frequently involved in rollovers. The influence of sloshing cargo on the lateral dynamics of the vehicle, and thus its stability, could be described in view of three primary factors:

- The inertia associated with the liquid bulk;
- The lateral shift in the centre of mass;
- That the movement of the liquid coincides with the movement of the vehicle.

In addition the slosh force amplitude can increase with a decrease in the fill volume[8].

6.13 The use of transverse baffles significantly reduces the amplification factors not only in the longitudinal axis but also the lateral axis. The shape of the tank is also a factor in the behaviour of the water as the dynamics of water in rectangular tanks is different to that of circular or rounded tanks.

6.14 The dynamic behaviour of liquid defined in terms of force amplification factor is a function of the fill level, magnitude of the acceleration field and the baffle configuration and design.[9]

Tank Construction in Standards

6.15 The French standard 004/2005 gives information on the design of baffles and says:

---

[7] Moiseyev, N.N. & V.V. Rumyantsev. "Dynamic Stability of Bodies Containing Fluid." Springer-Verlag, 1968.

[8] Experimental Study of Liquid Slosh Dynamics in a Partially-Filled Tank, J. Fluids Eng. July 2009, Volume 131, Issue 7.

[9] Role of transverse baffle designs on transient three dimensional liquid slosh in a partly-filled circular tank, Korang Modaressi-Tehrani, S. Rakheja and I. Stiharu. CONCAVE Research Centre, Concordia University, 1455 de Maisonneuve West, Montreal, Québec, Canada H3G 1M8.

"To limit liquid movement inside the tank during vehicle displacements, the vehicle must be provided with at least one vertical partition or slosh baffle in the longitudinal axis of symmetry of the vehicle. Vehicles with usable water capacity >= 4500 liters must be provided with enough transversal partition baffles to define compartments containing a water mass less than a quarter of the transported water mass, without exceeding 2000 kg.

These partitions are fixed or dismountable. Passages reserved for liquid must be sufficient to supply the pump at its maximum flow."

6.16 This provides an outline of the baffle and the number of partitions it should contain, however there are other considerations, such as:

- The height of the baffle, full height or with gaps top and/or bottom;
- Holes in the baffle, their size and number;
- Vertical or horizontal baffles;
- Properties of partially filled against fully filled tanks;
- A means of measuring sloshing.

Vehicle Specifications For Tanks

ICAO

6.17 The ICAO Airport Services Manual, Part 1, Rescue and Fire Fighting sets out guidance for the RFFS on vehicles. It briefly mentions in Chapter 5, Section 5.9 that a preferred type of tank should be specified in the specification for a RFFS vehicle. However, there is no further mention in the document about tanks or their features e.g. size, shape and baffling.

6.18 The ICAO guidance does include a tilt test of 28^0 or 30^0 depending on the size of vehicle, however it is not known if these figures are based on any mechanical or dynamic tests.

NFPA

6.19 The USA-based National Fire Protection Association in NFPA 414 – Standard for Aircraft Rescue and Fire-Fighting Vehicles, sets out requirements for tanks and stability. However, it does not include any requirement on baffling or tank position. The acceptance criteria on cornering stability involves manouvering the vehicle and relying on the driver's judgement as to the maximum safe speed.

France

6.20 The French National Commission for Airport Safety Equipments in its specification 0004/2005 sets out requirements for the baffling of water tanks.

The Sloshing Solution

6.21 If we look at the three primary factors in 6.12 above, the first two can be influenced by tank design and baffles whilst the third will be most influenced by the actions of the driver.

6.22 The mechanics and forces involved in a vehicle rollover are interlinked and follow the "Swiss cheese" error model. The way to tackle the factors that come together is by driving down the risks with each and ensuring that they do not coincide.

6.23 Table of Possible Remedies:

Factor	Problem	Remedy
CoM	High weight and CoM make the vehicle unstable.	Lower and spread the weight across the vehicle.
Sloshing	The inertia of the liquid causes the CoM to move and the vehicle become unstable.	Restrict the movement and effect of the liquid by reducing tank size, baffles or other restrictors to movement such as inhibitors and/or design the tanks to limit the amount of sloshing e.g. by using circular or rounded tanks.
	The coinciding of the movement of the vehicle and the movement of the liquid.	Control the movement (Roll) of the vehicle with suspension systems. Monitor the liquid movement and the vehicle movement. Inform the driver when an unstable situation is developing. Stop the vehicle moving unexpectedly such as gear changing on automatic gearboxes.
Amount of liquid	Causes sloshing.	Reduce the amount of liquid or increase the number of vehicles. The use of Level C foam will reduce amounts by 22%. Future advances in foam technology may allow further reductions in water and media quantities.

Future Developments

Level C Foam

6.24 The current proposal that is being considered within ICAO is for an enhanced fire fighting foam called Level C. The gains from using this improved performance foam are 22%[10]. These gains can provide additional safety value, improved performance, less media or a combination of each.

Compressed Air Foam Systems (CAFS)

6.25 Foam produced by most vehicles to be used for aircraft rescue and fire fighting will utilise solutions, either in pre-mixed forms or by the use of a proportioning system, which are delivered at a predetermined pressure to nozzles. The pressure may be created by a

[10] ICAO Level C tests, September 2008, UK CAA.

pump or, with vehicles of smaller capacity, by a compressed gas source, usually either dry nitrogen or dry air. In all cases the system will produce optimum foam only if the solution is delivered in the appropriate concentration and in the correct pressure range to the nozzle or nozzles. The operational advantage of aspirating nozzles lies in their ability to produce optimum foams both at the vehicle monitor, and where necessary, through extended hoselines, provided that the pressure is adjusted to compensate for any friction and contour losses contributed by the hose-lines. Some technologies provide expansion of the solution within the vehicle by the induction or injection of air, by various methods, all of which produce effective foam. The advantages of injecting compressed air either from cylinders or compressors within the foam system are that foam can be propelled further and that the foam produced is of consistent quality. These systems are normally identified as Compressed Air Foam Systems (CAFS).

Canadian Research

6.26 The National Research Council Canada (Research report 147, January 2004) carried out tests for the “Comparison of the Fire Suppression Performance of Compressed-Air Foam with Air Aspirated and Unexpanded Foam Water Solution”. It its conclusion the report says:

“The extinguishment densities for the gasoline tests demonstrated that CAF could extinguish the fire with at least 60% less material than the air-aspirated foam using Class B solution.”

6.27 Gasoline and Kerosene have similar energy characteristics (energy content 47 Mj/kg).

CAFS and Level C

6.28 It is established that level C allows a 22% reduction in foam and CAFS has the potential for a 60% reduction. Therefore for a 10,000 litre vehicle the theoretical saving could be:

- Level C Saving 10,000 less 22% = 7,800
- CAFS Saving 7,800 less 60% = 3,120

6.29 The above CAFS figures are theoretical; there would be a need for testing to establish practical figures.

Conclusion on Media

6.30 There is not one solution to the issues that arise from the amount of water currently required to be carried on an RFFS vehicle. The main factors are based around the Centre of Movement of the vehicle and the sloshing of the fluids in the tanks. To summarise, the features that affect the stability of RFFS vehicles relating to the media carried are:

- The weight carried and its distribution;
- The design of the tank shape;
- The design of the tank baffles.

6.31 Other factors are:

- The vehicle design, in particular the suspension;
- Driving;
- The environment in which it is being driven.

6.32 The conclusion is that all of the above factors can come together to cause a rollover, so the solution is to reduce the risks with each of the above to as low as reasonably practicable[11].

Recommendations

The Weight Carried and its Distribution

6.33 All the vehicle standards mentioned in this report deal with weight distribution and Centre of Mass and include tests for measuring roll. There is a need to focus on one tilt table test, the SAE J2180, as being best practice. There is also a need for dynamic tests and figures for the distribution of the weight. The recommendations regarding vehicle design are best dealt with and are included in the chapter on vehicles. The weight carried on a vehicle has a direct effect on its stability and it is clear that any reduction in weight will reduce the risk.

Recommendation 5

Where possible, without affecting the fire extinguishing capability, the amount of media carried should be reduced. Advancements in media efficiency should be considered in standards. This would provide a greater choice in terms of vehicle types and tank capacities.

The Design of the Tank Shape

6.34 There has been much work on tank design in other transport means and there are design standards for road tankers. It appears that none of this work has been applied to fire appliance tanks, whether RFFS or local authority. Therefore there needs to be work to apply principles established elsewhere to RFFS vehicle tank shapes.

Recommendation 6

The design of RFFS fire vehicle tanks needs to consider the shape of the tank and its effect on the sloshing of the fluid.

The Design of the Tank Baffles

6.35 All the standards reviewed in this report include specifications for baffles. However, on investigation none of them are based on specific research into the sloshing effect in tanks. There has been much work on sloshing and it should be possible to apply the principles from other tank designs to RFFS vehicle tanks.

Recommendation 7

The design principles of fluid tank baffles in RFFS vehicles should be established based on similar work conducted on sloshing in tanks.

[11] The Health and Safety at Work etc. Act 1974 requires the "Provision and maintenance of plant and systems of work that are, so far as is reasonably practicable, safe and without risks to health".

6.36 References:

a) Liquid Sloshing Dynamics, Theory and Applications, Raouf A Ibrahim, Cambridge University Press. ISBN 13978-0-521-83885-6;
b) ARFFS fire fighting vehicles; Common technical specifications. National Commission for airport safety equipments. 004/2005. V2R5. 13/07/2006;
c) http://www.stac.aviation-civile.gouv.fr/cnmsa/textes_cnmsa/gb/ARFFS_fire_fighting_veh.pdf;
d) Standard for Aircraft Rescue and Fire-fighting Vehicles, 2007 Edition. National Fire Protection Association (NFPA). NFPA 414;
e) Evaluation of Retrofit ARFF Vehicle Suspension Enhancement to Reduce Vehicle Rollovers, Federal Aviation Administration, DOT/FAA/AR-02/14, March 2002, http://www.airporttech.tc.faa.gov/Safety/Downloads/02-14_ARFF_Rollover.pdf ;
f) Experimental Study of Liquid Slosh Dynamics in a Partially-Filled Tank, J. Fluids Eng. July 2009, Volume 131, Issue 7;
g) Role of transverse baffle designs on transient three dimensional liquid slosh in a partly-filled circular tank, Korang Modaressi-Tehrani, S. Rakheja and I. Stiharu. CONCAVE Research Centre, Concordia University, 1455 de Maisonneuve West, Montreal, Québec, Canada H3G 1M8;
h) Aviation Fire Fighting Media - Developing Future Standards, CAA paper, S Webb, July 2010;
i) International Civil Aviation Organisation (ICAO), Airport Services Manual, Part 1, Rescue and Fire Fighting, Third Edition – 1990, Doc 9137-AN/898. www.icao.int ;
j) Safe Operation of Fire Tankers, Federal Emergency Management Agency, http://www.usfa.dhs.gov/downloads/pdf/publications/fa-248.pdf .

Appendix A **Driver Training Flowchart**

Flowchart	Requirements	Source
Do the RFFS vehicles proceed to incidents at high speed?		
No	• Vehicles should be fit for purpose • Vehicles to be maintained • Drivers competent • Records kept	• Driving licence – national and/or airport • Airport rules • Byelaws • CAP 168, Ch. 8, P 4.5
Yes		
A "Response Safe System of Work" must be in place.	High Speed is defined as "Any speed, which exceeds that of any statutory speed limit in force on the road at that time or exceeding any speed restriction on the vehicle being driven. The speed may also be below the speed limit but in excess of a speed of other vehicles using the road at that time." In essence, when an emergency driver is travelling faster than most other traffic and needs to overtake or the other vehicles to yield, they will be driving at high speed.	Joint Emergency Service High Speed Driver Training Advisory Group report 2008.
	A Response Safe System of Work includes a number of elements that must come together to deliver an effective and safe response. A comprehensive Hazard and Risk Analysis should be conducted over the optimum response routes within the aerodrome boundary that RFFS vehicles are likely to use to achieve the Operational Objective.	Civil Aviation Publication (CAP) 168 Chapter 8, Para. 4.5 Competent Staff should be in line with CAP 699 Unit AFF6 Aerodrome Fire Vehicle Training Guide – to be developed.

Will there be a response on the "Public Highway"?		
No	An assessment of the 1,000 metre area and any difficult environs should be carried out. Special procedures and equipment should be available.	Cap 168 Chapter 8 Section 24 Cap 168, Chapter 8, Para. 24.4
Yes At "High Speed"? No	• Vehicles road legal • Drivers licenced • Drivers competent	• Road Traffic Acts • DVLA requirements • DSA requirements (CPC) • Competent Staff should be in line with CAP 699 Unit AFF6
Yes	• Vehicles road legal • Drivers licenced • Drivers competent	As above plus: • Compliance with national "High speed driving" Code of Practice