An Examination of Potential FST Hazards Regarding the Usage of CF/Epoxies for Fuselages in the New Generation Commercial Aircraft Such as the Boeing 787 and the Airbus 350

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Dedication

This extended paper and its appendix are dedicated both to my sister, who has always been my constant, bravest and wisest counselor and guide throughout my life and to my wonderful and loving wife, best friend and partner who has endured much during my research and writing. With all love, I hope that neither of you are disappointed in the result.
Revision June 2010

The original of this draft paper was written in January 2008 and since much has ensued since that time, it is considered timely to update the original with later inputs and published papers to ensure timeliness, clarity and completeness. My technical position is, of course, unchanged from the original draft, but a series of further data points, incidents and reference papers has been included as deemed helpful for the reader.

To firmly establish that I am not going to be overly concerned with our all too enervating PC climate, I wish to also emphatically note that the utility of synecdoche is employed throughout by the author to avoid hurt feelings amongst any tender souls reviewing this extended paper and its appendix.

Examples of additions include recent papers by Dr. Timothy Marker of the FAA and his co-workers and various new papers and additional research are added for review, particularly, I note, the AGARD conference proceedings (AGARD -CP-587) from the Propulsion and Energetics Panel concerning Aircraft Fire Safety, 88th symposium Dresden, Germany 14-17 October 1996. In addition, I now cite Dr. Marker's interview with Wayne Rosenkrans as published in Flight Safety Foundation in Aerosafety World dated April 2008 and I have some major disputes with the rewriting of history contained therein and I am hoping that Dr. Marker was incorrectly quoted.

Several other papers are added and discussed such as; the excellent and harrowing Aircraft Incident Report by AAIB regarding the Manchester Boeing 737 fire tragedy (Ref: report number 8/88, crash occurred on 22nd August 1985), “Post-Fire Damage Assessment of a Composite Wingbox”, authored by S. Yarlagadda, A. Chatterjee and J.W. Gillespie Jr. of the Center for Composite Materials, University of Delaware plus other authors from Applied Research Associates and Lt. David J, Mcgraw, AFML, Airbase Technologies Division, Tyndall AFB (ref: AFRL-ML-TY-2004-4516), dated May 2004, plus papers from Dr. Louise Speitel of the Fire Safety Branch of the FAA W.J. Hughes Technical Center, Atlantic City, New Jersey and the draft FAA AC document for composite commercial aircraft is included.

In addition the survivable crash tables have been updated to reflect the latest data from the excellent site Aviation Safety Site (ref; www.aviation-safety.net) which, under the superb leadership and efforts of Dr. Harro Ranter is a leading source of aircraft crash data presented in this paper plus further crash and incident database information from CSRTG Aircraft Accident Database (Ref: rwgcherry-adb.co.uk) as sponsored by the FAA, British CAA and Canadian, Transport Canada.
Preface

As this paper is the probable culmination of many decades of my aerospace and composites engineering career, during which I have published several dozen papers, I request your indulgence in allowing me to deviate from the usually expected and demanded formal style of engineering papers. This is done deliberately, but as I am now in my 70’s, I can hopefully claim the privilege of writing this in a more personal style than that normally expected by SAMPE and other Societies.

I have (please note lack of the third person), during the course of my career met, worked for and enjoyed friendships with many outstanding individuals both within and outside of Aerospace and I want their contributions, help and guidance to be recognized in this, quite probably, my final formal paper. Again this is a departure from the norm, but please indulge me.

First, I wish to acknowledge and thank Mr. Ron C. Gilbert, Mr. Stan Johnston and Professor Glover-James all late of De Havilland’s Airspeed Division. They taught me much regarding engineering and the responsibilities and duties of engineers and I am forever grateful for their knocking some sense into my totally inexperienced engineering apprentice head. Next, I wish to thank Dr. Larry Ilcewitz of the FAA for all his encouragement, help and guidance and all thanks and appreciation also go to Mr. Mike Dostert of FAA for their kind and wise guidance and cooperation during the past three or more years.

During the course of my composites engineering career I have had the honor of working for an outstanding leader and inspirational engineer, Mr. Chuck Kahler, the now retired VP and Head of Boeing Wing Responsibility Center (WRC) at Boeing Commercial Airplane Division. Chuck embodies all that it best, ethical, intelligent and wise in our industry and I would be remiss not including Mr. Kahler in this dedication. He serves as a beacon of sanity, expertise, integrity and the highest ethics and, in this engineer’s opinion, when Chuck took early retirement, Boeing lost its finest and best leader. Other Boeing leaders and engineers that I wish to include in this dedication include, Julius Johnston, a highly talented and very wise executive and Mike Turek, my direct boss at Boeing who tolerated my all too frequent reports and visits and who guided and helped me with the outstanding advice and the highest ethics during my three years of Boeing consulting activities. In addition, I salute Larry Jarman, a fellow survivor from the 1959 A.V. Roe CF-105 Black Friday debacle and a superb and wise structures engineer who helped guide Nikkiso and myself over many years. Next, I sincerely thank Dan Bushacher who greatly helped me during my long association with the Boeing PP&S Division under the outstanding overall leadership of Mr. Chuck Kahler. Similarly, I also salute the memory and career of Dave Christiansen, the wonderful manager of engineering at Boeing PP&S.

Many others have guided and taught me during my career, such as Vince Paul, Chuck Leong, Bernie Lovegrove, Bill Hawker and Dr. Sol Singer at Lockheed MSC. I also wish to recognize and honor Professor Ed Wilson and Professor Ray Clough at UC Berkeley who taught me FEA programs and gave me great support and encouragement back in the early 60’s over the initial opposition of Lockheed R&D who were locked into finite difference methods and of Lockheed Burbank who were
stuck with the stately, slow and inefficient force method under closed shop programming at that time. Ed Wilson, Len Hermann and Ray Clough taught me a multitude of matters, but particularly why to mistrust computer programs and output until rigorously cross-checked and verified concerning assumptions and modeling and machine accuracy. I also learned to insist that my engineers perform simple equilibrium balance checks prior to even bothering talking with me with their reams of doubtful IBM outputs.

In addition, there was Herb Jenks, a superb, highly imaginative and admirable composites manufacturing engineer, decades ahead of his peers. Herb regretfully died far too young, and I honor and Herb.

Bill Eddy, late of Bendix is a superb engineer as are Geoff Bidwell and Jim Helms together with the cerebral and highly intelligent Ben Sandilands deserve my high praise. Regarding Fiberite, sadly long gone Fiberite, I had fine working and personal relationships with Mike Scott and Ben Miller who with his brother, Rudi was an outstanding pioneer in composites.

There are many others that I hold in the highest admiration and esteem including: Professor Hussein Kamel of Arizona State, Professor Len Hermann of UC Davis, Mr. Carl Holdren and Mr. Carl Bowman of GE Aircraft Engines, both superb engineers and wonderful friends, Mr. George Medawar ex-Rohr Program Manager who has always guided my career since our Malton days, a dear friend past, present and always. Next I wish to recognize and honor, the superb Dr. Peter Beardmore, ex-Ford R&D manager, Peter Oswald of Akzo, Arthur Babbington, now retired from Australian CAA and a superb vintner and friend, Derek Toogood, ex-Managing Director of Courtaulds America, Richard Hadcock and Sam Dastin of F-14 horizontal empennage boron/epoxy fame, Alan Binks of B.F. Goodrich, Dr. Larry Ashton ex-GD/A, a brilliant composite theoretician, business leader and author and, of course, Gary Turner in his Munich palace. I honor and thank them all.

There are many others, of course, to be recognized including Mr. Shinya Asada, a great friend and an ex-Nikkiso Company Ltd engineering manager, now with Boeing, Japan and serving as an FAA OAI QA representative. I would also recognize and honor the outstanding research and leadership of Dr. Kazuhisa Saito, retired Managing Director of Toho Rayon, now Toho Tenax who I accompanied on many travels and adventures throughout Japan and who is a great friend and mentor for me in composites.

Further, I wish to pay tribute to the superb leadership of a great and wise leader, Masahiko Hatano, ex-Toho Rayon and retired President of Nikkiso Ltd.

In addition, I pay tribute to the memory of Bud Townsend, ex-UCC who taught me a host of things, composites, ethics and guided and taught me, as did Jon De Vault, Jon Poesch and Nick Spencer of Hercules and Roy Tiley of Narmco and Aldila. Finally, I wish to thank and pay tribute to Antoine Vieillard of Airbus and Aerospatiale, Rich Moulton, a leading chemist and researcher concerning a wide range of matrices and a host of sticky things together with Louis Daffix and Pierre Betin of SEP, Bordeaux, who were always kind, solicitous and exceptionally wise.

I wish to also honor the outstanding work of SAMPE members over the past turbulent and challenging decades and to recognize a few of composite pioneers and leaders which represent a sampling of SAMPE Fellows, both living and deceased with whom I have had the pleasure to interact with, learn from and know during my
composites career. Specifically, I would cite the following Fellows as teaching me and representing all that is best in our diverse composites field; namely, the outstanding contributions of George Lubin, Steve Loud and Marty Burg, John Van Hamersveld, Dr. Carl Zweben and Dr Christos Charmis. Clearly there are many others equally worthy of citation, but these SAMPE fellows stand out in my memory.

Obviously, there are many more excellent engineers and leaders in composites that I have omitted in this preface and to all these engineers I sincerely apologize, but they know who they are and I honor them all.

Finally any and all errors contained herein my responsibility and mine alone

**An Extended Executive Summary**

This detailed and voluminous paper, together with its associated appendix, presents in detail my major findings and research concerning public safety stemming from the widespread usage of epoxy based CFRP for the fuselage and wing structures of the Boeing 787 and the Airbus A350. I make no apology for the length of these papers as this issue clearly deserves full public scrutiny and detailed assessment and review by my aeronautical researchers and peers.

Based upon all my research and those of many others in the composites, I have concluded that a major potential safety hazard exists and that it is one deliberately not being properly addressed either by Boeing or the FAA for the 787 aircraft.

To clarify for all readers, a lower half fuselage insulation blanket scheme has been developed and adopted by the FAA both the Northwest FAA and the William J. Hughes Technical Center, Atlantic City. This scheme was developed in parallel with the 787 aircraft and were finally promulgated in 2008 with such FAA Advisory Circular 25.852.2 “Installation of Thermal Acoustic Insulation for Burnthrough Protection” and others such as Final Rule NPRM 2003, 2009.

I have no particular argument with this lower half of fuselage insulation scheme as it is certainly better than nothing, although it is clearly totally inadequate for any flip-over or roll over crashes, such as are well known for MD-11 and L-1011 aircraft in particular. However, there is a major inherent flaw in this approach, as it can only be of any benefit regarding enhancing passenger survivability if the fuselage remains intact, unopened and not compromised in any manner via opened exits or other fuselage damage. This assumption by the FAA and Boeing flies in the face of the history of survivable aircraft crashes, the majority of which experience suffer ruptured, penetrated and opened fuselages.

Let me be very clear regarding definitions at the outset of this very long paper concerning FST hazards for the 787 and potentially also the A350. I define herein generally as ruptured fuselages for ease of writing, but this clearly encompasses and also includes broken, compromised, opened via emergency exits or doors and all instances where the fuselage is **not intact and the cabin interior not sealed** from the ingress of epoxy generated FST products and fires. **Other authors employ different terminologies to define these conditions such as “severe impact damage”, but I trust with this definition the distinction between the assumed FAA intact fuselages as deemed protected via lower half fuselage insulation schemes and my key and numerous**
concerns focusing on the real world of survivable commercial aircraft crashes is brought into clear and immediate focus for all readers.

It is my unequivocal position that the vast majority of survivable crashes are in the ruptured, opened and compromised category, a category which the FAA refuses to address. In this finding, clearly it is incumbent upon me to fully justify my technical position and not engage in polemics and other nonsensical gadfly activities. Thus, I have performed much additional research to define “the clear minority of survivable crashes” as I claim is the case for any FAA intact fuselage assumptions. Further, I must objectively justify my claim that clearly the FAA and Boeing are both totally failing to address the ruptured, compromised and open fuselages which represent “the high majority of survivable crashes” to the best of my knowledge.

Hence, I submit as objective third party evidence, the paper submitted at the AGARD 1996 October Conference entitled : “A Computer-based Simulation and Risk Assessment Model for Investigation of Airliner Fire Safety”, authored by P. Macey and M Cordey-Hayes of The Innovation and Technology Assessment Unit, IERC, Cranfield University, Cranfield, Bedfordshire, UK in association with A. F. Taylor and W.G.B. Phillips, formerly of the Fire Research Station, UK, Cranfield Aviation Safety Center, College Of Aeronautics, Cranfield University, Cranfield, Bedfordshire, UK.

The paper was presented at the PEP Symposium on 'Aircraft Fire Safety”, held in Dresden Germany, 14-17 October 1996 and published in AGARD CP-587. The authors are all outstanding leaders in the fire safety field and particularly well known in the aircraft fire safety community. I note and cite that in the paper's section entitled “The Study of Past Accidents”, they present the findings of their long and extensive accident data gathering and research and present “An Accident Scenario Tree” which cites the overall results of a 12 month data survey. The results are:

1. The Survey covers Fire Survivable Accidents from 1958 to 1994 and cites a total of 217 applicable cases.
2. Significant Fuselage Disruption (AKA ruptured, penetrated,, opened and compromised fuselages) is cited in 136 cases
3. Cases with no significant fuselage disruption are listed as only a minority of 43 cases

(Note; there appears to be a very minor error in addition in the original cited paper or by myself).

Clearly, and to my mind, irrefutably, the percentage of significant fuselage disruption (i.e., ruptured and compromised fuselages) opened to ingress of FST hazards into the critical cabin occupied area is 73%. In contrast, “no significant fuselage disruption” (presumably as espoused under Dr. Marker's and Dr. Speitel's INTACT fuselage scenario) totals a mere and minor 23%. This is a factor of over three to one and shows that the currently advocated FAA and Boeing regulations for insulation of the lower half fuselage and all their joint and separate burnthrough tests are only addressing a small minority of survivable fire crashes whilst ignoring the vast majority of such cases.

Researching this subject in depth and preparing this paper, I have also found and cite many survivable commercial aircraft crashes via several excellent and
reliable sources and found that the vast majority of such survivable crashes had ruptured, opened and compromised fuselages.

In my early communications to the FAA Northwest, I originally listed over 70 such ruptured and opened fuselage crashes and specifically ignored all that were intact. In this final and updated revision, there are a total of over 110 ruptured, opened and otherwise compromised commercial aircraft fuselages in survivable crashes and incidents. These survivable accidents are listed in Table 1 of this updated paper, but the author also urges the reader to fully review the updated Appendix as this also contains other survivable crash data.

I have ONLY listed by my criteria survivable crashes which is consistent with all my earlier inputs to the OEM's and certifying authorities. A reasonable person, will, I think, agree that this constitutes a broad enough database to adequately and fully support my technical and safety position.

Obviously, the moment that a fuselage is penetrated, opened or ruptured, new FAA lower half insulation scheme is rendered totally useless in preventing the ingress of toxic, smoke laden epoxy based combustion products into the cabin and impending or preventing the escape of passengers and crew in survivable crashes.

This lethal ingress occurred in the important and highly researched Manchester crash of August 22nd 1985, as it also did to a lesser degree for the Air France Malton overrun crash in August 2005. Further, in this revised paper I have listed survivable crashes since mid-2008 and note that the American Airlines crash at Kingston, the British Airways 038 Heathrow undershoot and the Turkish Airlines crash at Schipol all constitute recent salient examples.

In contrast, I can only find FAA and Boeing testing for intact fuselages for the 787, which flies in the face of the real survivable crash world. One of the latest is the Marker and Speitel paper “Development of a Laboratory-Scale Test for Evaluating the Decomposition Products Generated inside an Intact (my bolding) Fuselage During a Simulated Postcrash Fuel Fire”, (reference DOT/FAA/AR-TN07/15, dated August 2008). In spite of much research over the past three years, nowhere can I find any FAA tests on ruptured fuselages involving 787 cf/epoxy composites. There were a series of opened fuselage FST fuel fed tests conducted in the 70's and 80's. These early tests clearly determined the lethality, toxicity, smoke hazards of aircraft cabin interiors which finally resulted in the banning of epoxy based CFRP for interiors by the FAA and other certifying agencies. I have also researched and found composite wing box fire tests conducted by University of Delaware and Tyndall AFB researchers in 2004, as cited and reviewed, however no detailed FST testing was conducted by those researchers.

Upon belated publication of this draft paper and its accompanying appendix, I anticipate that the corporate and PR staffs of Boeing will rush to the Seattle area ramparts hollering “Boeing is totally committed to safety and the 787 fully complies with all the latest and enhanced FST requirements of the FAA”. Similarly, I anticipate responses from the political leadership of the FAA claiming “We have demanded new and rigorous fire standards and lower fuselage insulation and Boeing has successfully met all such requirements” or similar tosh. However, both Boeing and the FAA are, I believe, being specious in such claims and are, in fact, totally ignoring and refusing to test a ruptured, opened, or otherwise compromised 787 fuselage in a pool fed fire under this
“worst case but survivable conditions”, as even Dr. Marker and Dr. Speitel specifically recognize in their recent 2008 paper.

Thus, one can only conclude that in the case of the 787, speed of certification and rampant commercial pressures are trumping passenger safety and survival at both Boeing and the FAA. As far as I have been able to determine from either FAA or Boeing published literature, this circular argument in logic falls on stony ground with this engineer and, I would hope, many others.

It has recently been cited in a Bloomberg article dated June 6th 2010 that the UK's CAA believes that 80% of aircraft crashes are survivable. I would, without hope, as Eliot said, that this would quiet those amongst the public with far different and false perceptions concerning survivability in commercial aircraft crashes. The new rules edicted by CAA and EASA mandating the 16g rule for commercial aircraft seating are a significant step forward, just as was the earlier FAA's implementation of nitrogen fuel tank inerting over the standard and expected opposition of the airlines. I praise both agencies and personnel involved in successfully managing to edict these enhanced safety measures.

However, I would separately propose a far cheaper, less complex and more effective means to achieve 16g crash capability as some are pursing via expensive seat-belt mounted airbags while greatly enhanced passenger and crew safety as I discuss later in this Executive Summary. Frankly, the proposed safety belt airbags, as discussed in the Bloomberg article, strike me as far too complex and much too expensive. Keeping things simple always make sense to we engineers.

However, in the continuing rush to certify the 787, come what may, clearly the worst, but survivable case logic has been jettisoned in my view and both Boeing and FAA are off pursuing burnthrough and insulation solely on intact fuselages. This contention and its foundation is made explicit in this paper. However, I believe that my own data, coupled with cited excellent Cranfield study defy the present path of Boeing and the FAA.

It appears obvious that both the FAA and Boeing are refusing to conduct a full scale pool fire test FST on a ruptured or opened or compromised 787 fuselage reflecting the real survivable crash world. I find their position both technically and ethically untenable. I will be happy to hear of such a test being conducted and would hope that it would prove successful, but nothing to date gives me any such confidence.

Walt Gillette, now retired from Boeing, together with the FAA always claims improved safety for each new family of aircraft, but clearly the FAA lower fuselage insulation scheme is designed to allow certification by only addressing a small minority of survivable fire crashes and hopes to swish it through on such dubious grounds. By their refusal to conduct such a full scale FST test pool fire test on a ruptured fuselage, it appears that they are implicitly acknowledging that they fear their ability to successfully pass such a worst case, but survivable, test. Again, if Boeing and the FAA conduct such a rigorous and independent FST test successfully, I will be amongst the first to congratulate them, but such a test clearly does not seem in their current certification strategy to my knowledge.

We engineers can only gain confidence in the safety of our products by rigorous and worst FST case testing, just as was and is the case for cabin interiors since the 1970's and 80's. I would hope and anticipate that there are many dedicated engineers
at Boeing, Airbus Industrie, EASA, the FAA plus all other certifying agencies, together
with the NTSB and DOT Inspector-General's office  who will agree with my position
after closely reviewing this paper and its cited evidence in this critical matter of public
policy and passenger and crew safety.

Let me summarize my overall technical position:

1. CFRP epoxy systems are well proven laden with toxins, and smoke and
   are banned for interiors since the mid 1980's by FAA edicts and
   regulations.
2. CFRP epoxy systems auto-ignite around 300 degrees C (580 degrees F)
   versus auto-ignition temperatures of 1950 degrees F for aerospace
   aluminum alloys. Obviously, Aluminum alloys contain a bunch of nasties
   also, but the melting point of most aerospace alloys is in the 950 degrees F
   range, approximately 2X that of CFRP and the auto-ignition point of
   traditional aluminum alloys are 4X that of CFRP.
3. CFRP using epoxies as employed on Boeing 787 significantly add to the
   fuel load and immensely complicate and test fire-fighting times and
   personnel hazards as proven by the B-2A crash in Guam in early 2008
4. Attempted distinctions drawn by Boeing PR departments between
   “military based” and “commercial based” epoxies are not fallacious at best
   and are obviously designed to mislead the public. Such false distinctions
   can only be kindly labeled “a total load of codswallop”.
5. By far the majority of survivable crashes (73%) involve ruptured or
   opened fuselages which render the latest FAA insulation schemes useless
6. We banned epoxies for interiors decades ago due to their severe FST
   hazards, but now we build whole fuselages and wings based upon similar
   epoxy chemistry. Is this safety and progress?
7. Composite wings also present another significant in-flight fire hazard,
   particularly from uncontained engine disc and blade mishaps which need
   much further research, but are not addressed in detail herein. I believe
   Mitsubishi Heavy Industries with their MRJ reverting in 2009 to
   aluminum from cf/epoxy and the Chinese with their C-119 avoiding the
   majority of cf/epoxy and both keenly aware of, and wish to avoid these
   risks.
8. The FAA and Boeing continue to proclaim their goal that CFRP structures
   be equal to or safer than metallics, but their actions speak otherwise to me.
9. I would further note that even after the FAA and Boeing publicly
   proclaimed victory and improvement of passenger safety, EASA, the
   parallel European  certificating agency and indeed the FAA was still in
   January 2009 stating its concerns regarding; “fire behavior (toxic fumes,
   fiber release, in-flight, post crash strength)” together with
   “Crashworthiness” and adding that “Composite Utilisation is not to reduce
   safety level relative to that provided by metallic structure – but can be
difficult to define and quantify” and also added “flammability” and “cabin
   safety issues unique to composite materials plus much more to the mix”.
(Ref; “Composite Materials” Revision to CS XX.603 AMC (CS 23, 25,
In mid 2009, I formally proposed to the FAA that a full scale pool fire FST test be conducted on a ruptured or compromised 787 fuselage. No reply has been received to date from the FAA.

I would further note that I proposed the the FAA concerning their “Crashworthiness Special Condition” that a full scale test be conducted on a 787 fuselage with a forward velocity vector simulating a wheels-up landing or, by extension and over-rotation upon take-off. This was, somewhat inevitably rejected by the FAA with mutterings about “full scale testing is sometimes better simulated via models” and associated bureaucratic codswallop in this engineer's opinion. However, I note and briefly discuss in the next paragraph, the recent severe damage from serious tail strike and much aft fuselage damage (potentially allowing ingress of FST) if it had been cf/epoxy on an Emirates A340 on takeoff from Melbourne Airport in this regard. A question for both the FAA and Boeing, what would have happened if it was an auto-ignitable cf/epoxy 787 structure?

Here are some relevant details from the Australian incident, I draw the attention of both Boeing and the FAA to the Emirates tail strike upon takeoff caused by incorrect weight entries errors to the tune of a mere 100K lb. Specifically, I would like the authorities to now read and review the interim factual report, ATSB AO-2009-012.

This was an Emirates A340-541 taking off from Melbourne, Victoria on March 20th 2009. Due to the incorrect data entries, this aircraft took off with reduced power and only quick action by the pilot intervening and commanding TOGA power averted a tragedy. However the rear of the aircraft was still severely damaged per the report with cracked frames stingers and cracked aft composite pressure bulkhead and lower skin totally abraided away. Localiser and antennas were also broken off in this serious incident and I note that the ground speed during tail strike rotation was in the region of 170 knots. My concern with auto-ignition is clearly stated in this paper and I would again urge the authorities to conduct such a severe tail strike test on the 787 in the certification program, hopefully at somewhere like Edwards AFB in the desert with plenty of room for the flight test pilots to halt the plane from such a 170 knots tail strike as was the case for the Emirates A340 serious incident in Melbourne. All test components seem present, first reproducing an actual event which the FAA seems fond of, the potential penetration of the fuselage allowing ingress of any FST products into the cabin and cracking and fracture of the aft pressure bulkhead, cf/epoxy on the 787 and built by the same German maker as for the A340 to my knowledge. If the test is deemed too hazardous to the flight test crews, then it could be performed via remote control and with a pre-cracked aft pressure bulkhead. Thus, this test is also proposed in addition to the key full scale fuel fed ruptured, penetrated or compromised FST fuselage test. It is possible that such a takeoff tail strike test could be performed to cover both wheel-up landings as well as take off tail-strikes. The thoughts of the FAA and Boeing in light of the 2009 Melbourne incident are urgently solicited.

Further, so that I am not accused of just throwing out carping and criticism of the FAA and Boeing and not helping to solve the critical epoxy FST issue on both the 787 and A350, I hereby submit that my own technical position regarding improving
commercial epoxy based composite FST safety. This proposal is directed at mitigating the clear and irrefutable FST hazards posed by the 787 Toray 3900-2 epoxies via the extensive usage of intumescent coatings for all fuselage, wing and empennage structures. Such intumescent coatings are already well developed, understood and widely used for fire critical composite epoxy nacelle and pylon structures. I would also selectively employ such commercially available fire blocking products such as Fyre Roc marketed by B. F. Goodrich in Florida or equivalent combative fire blockers. These fire blockers already widely used on rapid transit applications face similar critical FST hazards as the 787 and A350 and on USN submarines for FST protection. Such fire blocking layers in would use around high wear and traffic areas such as around fuselage doors, windows, openings and emergency exits and interior ducting to enable a clear and safe egress path as feasible.

Next, I would ensure that automatic “g” initiated fire resistant Inconel or similar alloys shut-off valves be incorporated into all ducts and vents with any ingress paths to the cabin interior. Such valves would deploy automatically and would be backed up by a “Big Red Button” on both the flight deck and in the main cabin such that either pilots or cabin crew could activate them in an emergency. Details of such an approach I would happy to discuss with Boeing, Airbus Industrie, EASA or the FAA, of course. these proposals do not entail lots of research and development, but could be quickly tested and, if successful, certified and implemented.

And now for significantly improved interior passenger and enhanced evacuation capabilities, rather than just espousing goals, I would go two steps further and edict and implement a decent water mist system for all passenger and crew areas as recommended well over two decades ago by the UK Accident Board in their harrowing accident report of the Boeing 737 accident at Manchester for all new commercial aircraft with possible retro-fitting regulations also. The water mist system has much to commend it regarding simplicity and efficacy and was studied and extensively researched after the tragic 1985 Manchester accident, but never implemented by our all-too-often industry compliant and quietly quiescent certifying airworthiness authorities.

This advance in safety measure could well be implemented alongside editing rearward facing seats as have proved their value and worth over many decades in military and passenger transports such as VC-10’s, Hastings and others. These are well developed, reliable and impose no weight or cost penalties and can be supplemented and enhanced by four point seat belts to be used during both landing and takeoff phases. During cruise two of the straps, could, of course, be discarded for passenger comfort.

These simple measures would neither cost buckets of money that the airlines claim that they do not have, nor would require extensive development and testing as would be required by some expensive and complex airbags as are currently being proposed. This combination of four point seat belts and rearward facing seats would need no electronics or other complexities and cost no more or weigh no more. I believe such an approach would well suit future seat regulations in the 24g rather than the current 16 g proposals, again enhancing passenger and cabin crew safety. Clearly, this proposal is a simple, reliable and low cost approach, which would, I believe, save many injuries and lives annually on all commercial aircraft and could be quickly implemented.

This engineer finds it passing strange that safety minded Mothers are urged by consumer magazines to choose cars with the ability to fit rearward facing infant seats, our
society has many trains with rearward facing seats, we prize third row rearward facing seats, our pilots have four point belts as do many of our cabin crew, our cabin crew employ rear facing seats for survival and safety and yet some still say that “the flying public” would not accept such seats. Again, a load of codswallop comes to mind in this area.

There is clearly no weight penalty whatsoever, but saves probably hundreds or even thousands of lives annually and requires zero, repeat zero, R&D. Further it offers the prospect of going well beyond the newly studied and 16g seats, eliminates complex and costly airbags, is simple, efficient and demonstrably far safer. And where is our FAA, Boeing, Airbus, EASA, JAA leadership? Nowhere to be found in advocating such a series of reliable methods and employing such simple approaches. I have flown in VC-10’s and Tridents having rearward facing seats and, I note, they were much prized and sought after.

This five pronged approach to safety, I believe, is much more encompassing, rational and reflects the real survivable aircraft world far better than the very limited, questionable and inadequate present lower fuselage implementation scheme as developed and edicted by the FAA and Boeing.

I would, of course, still insist upon full scale ruptured, opened or compromised fuselage FST pool fed fire test on all aircraft models to demonstrate compliance and prove safety. Finally, in the longer term, I would like to go one step further and get rid of all FST hazardous materials on either the exterior or interior of all composite and metallic commercial aircraft.

Next, I would note that in many respects I feel empathy and sympathy towards the many dedicated engineers at Boeing. They were been dealt a very bad hand in that they were given no choice whatsoever of primary structural materials to be used on the 787. The only qualified material, by design some would say, was sole sourced from Toray via the BMS8-256 specification, specifically the Toray epoxy prepreg matrix 3900-2, just as had been true in the case of the earlier 777 empennage. To obviate any choice for the engineer is a very bad way to proceed on a major program, but Boeing corporate management made that choice with little or zero inputs from the engineers. Thus the engineers were faced with a hazardous flammable epoxy and had to try to make it work somehow. Square pegs and round holes come to mind in this regard. The FAA also worked with Boeing to dream up the lower fuselage insulation scheme, which is, as I have pointed out, fails to address the vast majority of survivable crashes on record and only deals with a very minor part of the overall survivable crash problem concerning epoxy based materials as I attempt to prove beyond a shadow of doubt in this paper and its appendix.

I also note that the chances of my influencing the current haste to certification of the 787 is around zero, but my responsibilities as an engineer dictate that I fully document my position and challenge the certificating authorities and Boeing to perform a full scale ruptured or compromised FST test.

In addition, as a composites aerospace engineer of many decades, I am not adverse to the usage of composites, providing that they are non epoxy based and that are used judiciously and with full awareness of the flammability and FST issues associated with such materials. For example, Airbus Industrie recently qualified benzoxazine from Henkel and Hexcel and I note that the Henkel press release states: “Here the composite
material must withstand high temperature exposure and **comply (with) Fire, Smoke and Toxicity (FST) specifications to avoid that any flame, smoke or toxic gases can enter the passenger compartment**” and “**As epoxy resin materials fall short in either temperature performance or flammability**”. Benzoxazine resins are phenol related and are are processed at the same temperatures as Toray 3900-2 epoxies. This is, of course a longer term solution, but one that offers a path forward for designers and researchers. In this area, I am not for a moment saying switch immediately to benzoxazines sand similar non FST hazardous matrices, but clearly with suitable research and development such resins and other advanced non-epoxy systems offer designers a clear path out of the current epoxy FST hazard trap and I advocate its study and development by the sane or saner members of our composite community. And it is not the only choice, of course, there are others, but clearly and irrefutably not the current hazardous epoxies on the 787 and B-2A.

My position is that, if Boeing and, by extension if applicable, Airbus Industrie, can both successfully pass such a full scale pool fire ruptured or opened fuselage test, they will receive my immediate sincere congratulations and thanks. However, if either fail such a full scale ruptured fuselage test or if they refuse to even conduct such a test, then it is my position that no CFRP fuselage commercial aircraft should receive certification as passenger safety dictates prudence and safety at all times and all epoxies that I am aware of fail that test regarding FST.

As a young squirt of an engineering apprentice at De Havillands I was peripherally involved at a very minor level in investigating some aspects of the Comet I fatigue crash tragedies and thus witnessed a once great company being destroyed by its hubris, making basic errors and taking safety too lightly. There is a clear lesson for others, if they are not too deaf or too proud to listen and learn. That incident taught me the primacy of safety and prudence at an early age and no engineer worth his degree should ever evade his sober responsibilities or choose any other philosophy in aerospace and all fields of engineering. The current example of the tragic and disastrous Gulf of Mexico oil spill is a stark reminder to all of us concerning safety and I would point out that it will not be the FAA's head on the chopping block, of course, but rather the OEM's, their suppliers and the airlines.

And, finally, as a note to posterity, my intent is that, in the event that both the FAA and Boeing continue in their ongoing refusal to conduct the vital and demanded full-scale compromised fuselage fuel fed fire prior to any final certification being granted, that this paper and its appendix will serve to eliminate or severely weaken any future excuses from OEM's, plus all certifying and safety authorities together with all operating airlines of such cf/epoxy aircraft, that they did not know the FST risks and could not foresee the severe potential safety hazards to the public flying in these aircraft.
Abstract

My intent in this paper is to present in detail the major potential FST hazards posed by the new commercial aircraft at Boeing for the 787 series and potentially at Airbus in the pending A350. First, I fully recognize that this subject is a controversial one and one that will raise ire in certain corporate, marketing and certification authority quarters, but as a composite engineer with many decades of experience it is clearly my duty to lay out for the composites community the potential severe FST fuselage hazards involved in these new all CFRP fuselages and their accompanying flammable CFRP wings and empennages.

For many, this paper and its associated appendix will be considered far too long, but there is much data and many sources to cite and quote, a long FST history to review and numerous survivable crashes to illustrate and review. This extended paper is in no respect designed as a ranting polemic or a Zola echoing “j’accuse” tract, but rather strives to progress in a logical sense presenting and citing all relevant materials in the reasonable and responsible engineering manner, but without ducking or avoiding direct and demanding criticisms where deemed necessary and germane.

First, in Section 1, I will review past history concerning FST in commercial aircraft. This subject has a long and detailed body of research data and reports that clearly defines the clear evidence that CFRP structures represent a major potential FST hazard. This hazard that I was involved with in the mid-70's finally led to the current strict FAA regulations banning epoxies from commercial aircraft interiors as implemented in the middle 80's.

In Section 2, several key CFRP papers and reports will be cited and examined in some depth including Dr. A. P. Mouritz and his excellent report “Fire Safety of Advanced Composites for Aircraft” (ref: ATSB Research and Analysis Report, Aviation Safety Research Grant – B2004/0046, dated April 2006) sponsored by the Australian Transport Safety Bureau. This is followed by a similar detailed paper concerning cf/epoxy hazards entitled “Health Hazards of Combustion Products from Aircraft Composite Materials” co-authored by Dr. Sanjeev Gandhi and Dr. Richard Lyon. More recently, important papers studying burnthrough of intact fuselages and accompanying test methods have been published by Dr. Timothy Marker and Dr. Louise Speitel in 2008, for example; “Development of a Laboratory-Scale Test for Evaluating the Decomposition Products Generated Inside an Intact Fuselage During Simulated Postcrash Fuel Fire”. DOT/FAA/AR-TN07/15, August 2008. These reports by Dr. Marker and Dr. Speitel are highly germane and represent the latest FAA thinking concerning CFRP in fires. I regard this as good research, but based upon a faulty premise, however, regarding actual survivable crash environments, as is common in all the past and ongoing FAA and Boeing efforts in the FST area concerning the 787 aircraft.

A NASA report entitled “Fire and Smoke Resistant Interior Materials for Commercial Transport Aircraft” from 1995 is also reviewed followed by some clearly excellent and detailed FST testing and studies conducted by EADS and Airbus Germany in the course of their recent Lufo2 (research sponsored by BMBF), DLR, and Black Fuselage entitled “Fire Smoke Toxicity: Burn through Resistance of Composite Fuselage” I have found their reports to be most imaginative, valuable and highly appropriate views and design insights and I focus on their sacrificial lower cabin
unpressurized impact absorbing work and their very insightful and innovative “Gondel” concept.

I also would specifically cite and commend to all readers for their detailed study and review a key report co-authored by the FAA in June 2002, namely “Combustibility of Cyanate Ester Resins” (Ref: DOT/FAA/AR-02/44), authored by Richard Lyon, William J. Hughes Technical Center, Airport and Aircraft Safety, FAA and Richard Walters and S. Gandhi of Galaxy Scientific Corp., Egg Harbor Township, N.J., dated June 2002. This report proves of exceptional interest, in light of my previously stated contention that far safer alternatives exist to the current Toray, Boeing sole-source 3900-2 epoxies currently being certified on the 787. It finds that; “Halogen containing polycyanurates exhibited extremely low heat release rate (please compare with Mouritz 2006 ATSB report re high and unacceptable epoxy flammability, HRR and peak HRR) in flaming combustion compared to hydrocarbon resins, aka epoxies, yet produced significantly less smoke and comparable levels of CO and soot” Also from the report; “The halogen-containing polycyanurates were difficult to ignite and had extremely low HRR”

Again, I invite all readers to compare these cited results with the well established and widely known combustibility, toxicity, high HRR and very hazardous FST products from all epoxies as documented herein. Exactly who does the FAA and Boeing think that they are fooling when it comes to the clear and present FST hazards for the materials used for the 787??

. The FAA and Galaxy Scientific Corporation report concludes with;

“The RD98-228 polycyanurate is the ONLY(my Caps and Bolding) conventionally processed thermosetting polymer, when used as a matrix resin for structural composites, is the only conventionally-processed thermosetting polymer reported (refs. 22 and 23) to have passed all of the fire performance requirements for use on US Navy submarines (ref: 24)”. This reference 24 is the demanding MIL-STD-2031 "Fire and Toxicity Test Methods and Qualification Procedure for Composite Materials Systems Used in Hull,Machinery, and Structural Applications Inside Naval Submarines, of 1991” for your reference.

So here we have the FAA fire safety experts themselves proclaiming that hydrocarbon epoxy resins cannot and do not pass the US Navy submarine requirements and this is in June 2002 after the 787 program was launched. But does this stop the same FAA from later proclaiming that epoxies are safe for aircraft, which is clearly not the case for concerning safety, flammability, fire, smoke, high HRR and toxicity? This nonsense is inexplicable and inexcusable and exposes, once again, the fallacious, foolish and evasive actions of both the FAA and Boeing concerning their attempted and planned certification of the 787 aircraft.

Other sources deemed worthy of review in detail will be cited to fully present the extent of the potential fuselage FST hazard in new commercial aircraft. Overall the intent of this section is to delineate and clearly define the potential for major FST hazards concerning cf/epoxy for fuselage usage in commercial aircraft.

The next section, Section 3, discusses the role, responses, Special Conditions published and finalized by the FAA and its proposed certification criteria based upon Section 25.856(b) and the proposed approach of equivalent level of safety
finding in accordance with SEC. 21.21(b)(1). This criteria will be reviewed in detail for its applicability and possible errors in approach and DOE (Design of Experiments). In addition, a key NTSB report is cited as a valuable and objective third party source and viewpoint of the role of the certification role and basis that the FAA should follow.

In the final main section concerning sources and papers, Section 4, I will present an extensive survivable aviation accident database culled from three excellent independent sources, www.air-safety.net (Ref. 25), www.airdisaster.com, (Ref. 26) and www.dnausers.d-n-a.net which represents a trio of well organized on-line resources and I wish to express my sincere thanks to them for carefully assembling such notable accident resources. The records and photographs, of past crashes, I believe, fully supports my contention that only by a series of full scale fuel fed fire FST ruptured fuselage or with open down wind exits and slides, again fuel fed and full scale in nature. I believe that such tests are vital to public safety, must be conducted prior to final certification and is a clearly a major matter of public policy as it relates to passenger and crew safety in the new generation of largely all composite primary structure aircraft.

I have deliberately selected a wide range of survivable crashes which all involved ruptured fuselages, opened exit and slide crashes, cartwheels crashes of large commercial aircraft and survivable crashes involving aircraft fires over the past decade. This is not a complete list, my any means, but suffices for a wide range of illustrative examples. I also list all involved airlines on a worldwide basis together with fatality and survival rates accident dates available from Ref. 25, 26 and 27. Clearly, at least in my mind, this refutes the refusal by FAA fuselage engineering group, to date, to stipulate that Boeing conduct such full scale and large scale open exit and ruptured fuselage tests for certification of the 787-8. Also this extended listing of survivable crashes is also intend to convince my fellow composite engineers that the requirements of 25.856(b), although key improvements re thermal insulation, do not fully meet the demands of the wide range of survivable crashes with respect to FST hazards for composite commercial aircraft.

There are “rumors” per my private FAA correspondence of such large scale testing being conducted in some form at Boeing although the FAA adds that “Boeing may not yet be ready to discuss their test results”, I find this hardly comforting and the FAA also has stated to me privately that “large scale fuselage structures FST testing is ongoing at Atlantic City, (the Marker and Speitel test, I assume), but adds that such testing “does not include the latest composite fuselage materials (i.e. 787-8 CFRP)”, again hardly comforting to this engineer. Any published FST results concerning ruptured or open exit composite fuselage fuel fed full scale from Boeing are unavailable to date, to my knowledge, but “all certification technical details are agreed between FAA and Boeing”, according to the Scott Carson of Boeing December statement in their webcast of December 11 2007. Thus, any test configuration, test methodology, DOE or published results are unavailable from Boeing and attempts to elucidate such date has been rebuffed to date with a statement to “contact Boeing PR and Communications office”. Clearly, it is in Boeing’s own vital commercial interest that the 787-8 be not only as safe, but indeed far safer, as was expressed by Mr. Walt. Gillette upon his retirement, than any earlier commercial aircraft and I fully expect that a good deal of internal Boeing test data exists, but without any published data a large question concerning the extent of
FST fuselage hazard remains unanswered. Equally, the FAA is under Congressional edict and law to enhance interior cabin safety by an order of magnitude over present standards and has active programs such as the SAFER program as will be cited in detail. However, in the face of consistent denial of FAA to enforce conduction of full scale fuel fed fire by Boeing under their 2007 issued Special Conditions and the lack of published detailed technical papers by the both Boeing and FAA to date these issues leave the composites aerospace community with a wide-ranging set of FST hazard based questions. It is the intent of this paper to actively encourage a wide ranging and rational technical debate within the composites aerospace community to fully address and assess the extent and seriousness of the potential FST hazard posed by new all cf/epoxy fuselages and their associated wing and empennage structures in the hope of ensuring that passenger safety is enhanced not diminished for the new CFRP aircraft and fuselages on the Boeing 787 series (and potentially also on the Airbus A350 aircraft if that aircraft uses CFRP as seems probable at this point).

I note that I have other strong composite design and structural concerns beyond FST for the new generation of commercial aircraft; including, particularly, differential CTE issues engendered by usage of GLARE FML materials on A380 coupled with loss of in-plane shear stiffness, bond line issues and fatigue concerns.

As an aside, my background in hybrids goes back to the 70’s whilst consulting with Hysol. I thus became involved in an ill-advised NASA initiated boron/epoxy bonded hybrid program to reinforce Lockheed C-130 main spar caps which were suffering from fatigue failures in service. This program was quietly dropped after it became clearly evident that the large differential CTE between aluminum and boron/epoxy was far too great and that bonding or fastening over a 130 foot span was totally impracticable. This is a major problem in all aircraft combining traditional aluminum alloys with CFRP and I wrote to Mr. Mike Dostert of FAA Northwest in April 2007 detailing my concerns in this area.

In similar fashion, I oppose all FML’s that involve hybrid materials where high CTE differentials are present as such hybrids create substantial fatigue loadings, not due to flight loads, but solely based upon the FML’s differential CTE’s and material characteristics. Examples include; cf and aluminum, Kevlar and aluminum and glass and aluminum (this is the current GLARE material). ARALL failed due to high CTE differentials, fire issues and poor bonding of Kevlar. Now we have GLARE which suffers the similar differential CTE defects in my mind, but with somewhat better bond allowables than ARALL. Such FML materials are fighting with itself due to temperature fluctuations leading to fatigue issues and potential disbonds. And I note that these CTE induced stresses are totally additive to any or all flight loads. The FML is fatiguing itself throughout its life due to such self-imposed stresses as well as suffering from significantly lower in-plane shear stiffness and strength and lower bearing allowables. I find it highly significant that Airbus never even considered GLARE for the A350, to my knowledge, for any of the several design iterations leading to the present composite A350 program. I alerted the FAA to this GLARE based differential CTE problem in April 2007 and also alerted them to the general issues arising from differential CTE problems arising from combining traditional CFRP alloys with CFRP.

I was later told by that agency that a letter to EASA was written and that “the A380 GLARE material will be monitored in service”. I note that Alcoa took out a license
for GLARE, but, fortunately, no commercial applications in the United States have resulted to my knowledge. Now I hear rumblings of GLARE-2 and other similar hybrid FML’s, but this engineer just sighs and will leave it to others to debate that issue and I have enough to focus on concerning the potential major FST hazards associated with CFRP fuselages.

A similar CTE issue exists for the Boeing 787 with the current cited usage of aluminum ribs in the Boeing 787 cf/epoxy center wing box and for both manufacturers the very poor tensile sigma 3-3 properties and all other out-of-plane low properties of composites represent a great and ongoing challenge as the latest 2009 six month delay debacle at Boeing proves. Similarly, lightning, galvanic corrosion, blunt force damage are major issues just as long term maintenance and QA and repair issues must be of concern. However, in this draft paper and its appendix, I will only focus upon the FST issues for composite fuselages, flammable wings and associate composite structures, which represent critical and vital safety concern by themselves. Further, recently it has been revealed by Boeing that a major problem exists in its fuselage shear ties due to CTE problems which has caused their replacement on all aircraft. Boeing stated that this problem was only discovered in December 2009, so clearly my warnings from April 2007 were ignored at Boeing.

In this safety of passenger and crew area, I unapologetically hold strong views based upon my FST and composites engineering experience and research, but I hope by presenting the evidence carefully and sequentially in a logical manner that I manage to remain somewhat objective, while being forthright in posing the key issues and citing all required evidence to support my position. I freely admit my bias and that is towards passenger and crew safety rather than commercial interests, for which I make no apology. My overall objective is present my composite peers and engineers with a well documented proof of potential major FST problems that I discern whilst steering clear of any tendentious or polemic tone. I fully recognize that my thoughts as presented and cited herein will be contentious, but only by presenting and citing my sources can we hope to move forward to a rational and well-founded debate within the composite aerospace engineering community regarding testing and certification stands and regulations for the new generation of all cf/epoxy commercial fuselages with respect to FST and passenger safety and egress in a survivable crash situation.

In summary, it is the intent of this paper to closely examine and rationally assess that high FST hazards exist for the composite epoxy based fuselage for the Boeing 787 and, if epoxy materials are selected, for the Airbus A350 also. My hope and intent is that this results in a rational and in-depth debate and publishing of all FST large scale and full scale test data on an expedited basis to both FAA and EASA and the technical community at large by Boeing and Airbus/EADS for peer review and clear and objective assessment. Only after objective and detailed assessment of all such critical FST data can we even contemplate certification in my opinion.

For clarity, as this is a very extended and detailed paper, I am including a Table of Contents to guide the reader and to define the scope and organization of this paper. This Table of Contents is presented on the following page for reference.
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Section 1: Background, History, and Notes concerning Auto-ignition and Material Selection Approaches

1.1 Some Background and History Concerning Composites and FST issues

Composites have established themselves well across a wide spectrum of uses over the past decades due to the efforts and research of many engineers and companies. Their merits have been well discussed in the literature and numerous examples can be cited concerning military aircraft, missiles, largely led by Hercules, LMSC and Thiokol, Brunswick and UTC, regarding composite rocket motor cases, helicopters and all composite sailplanes. In addition, all composite small aircraft such as the Beechcraft Starship, the Raytheon Premier and the newly developed Adam Aircraft 500 and 700 aircraft should be recognized and cited, but all are only in the small aircraft and small business aircraft field hence with fast passenger egress, while large all composite cf/epoxy fuselages clearly are in a totally different realm.

With respect to large scale commercial aircraft, composites have also been used successfully for empennages for two decades, notably led by the pioneering efforts of Airbus in the A300, A310 and A320 and its many successful variants and then for the A330 and A340 series for vertical and horizontal empennages. Boeing followed Airbus regarding composite empennages for the 777 series in the 90’s with equal success. These are outstanding successes by any measure and one of which our composites industry can be proud.

This paper chooses not to discuss those achievements in any depth, but looks at the other side of the coin and closely examines the potential hazards of all composite cf/epoxy fuselages in such aircraft, as epitomized by the Boeing 787 series. In fairness, this paper addresses potential risk areas rather than a backward glance at outstanding composites design, research and in-service experience. I would also point out that some of our past successes involved salient differences in service life, operations, maintenance and scale of passenger loads vis-a-vis new large commercial aircraft such as the A350 and 787 series. In addition, major mitigating safety factors exist in past applications which are clearly not present in the new generation of large commercial cf/epoxy aircraft and fuselages. I would, for example, cite the universal usage of ejection seats on military aircraft, auto-rotation and crushable lower structures provisions for
helicopters and few passengers and very large exits with trained personnel, no fuel in sailplanes and only a few corporate passengers in small aircraft allowing fast and rapid exit in most cases. I could also cite many other key differences regarding commercial aircraft operating on a worldwide basis. Clearly operating hours per year far exceed any military aircraft or helicopter, whilst limited exits, crowded passenger compartments are the norm and the life of commercial aircraft is measured in several decades with a useful life of thirty years being quite typical.

In addition, airline safety records, airline pilot training and airline engineering maintenance and repair standards all vary greatly on a worldwide basis as do rescue personnel training and equipment, airport safety standards and equipment and ATC controls. In the case of empennages, they are located well away from passenger exits and slides, but such is not the case with commercial all composite fuselages manufactured from cf/epoxy.

In the new series of commercial aircraft epitomized by the 787, we have crowded passenger compartments, high usage factors and hence potential safety issues can and do arise for all cf/epoxy fuselages and wings, (having their own in-flight safety structural issues) which have not arisen before and this requires that excellent full scale FST tests be conducted to substantiate and demonstrate passenger safety and egress and FST issues clearly become the dominant issue and we that we must address openly with excellent DOE of tests, peer review where appropriate and backed and enforced by strong certifying agency rules and regulations as have been developed for aircraft interiors over many decades and as discussed shortly. In summary, it behooves us as an industry to ensure, at all coats, that passenger safety on new commercial aircraft is not put at any adverse risk nor safety standards compromised in any manner. Given my experience in working on replacement of epoxies for aircraft interiors due to high Heat Release Rates and Flashover fires during the 60’s and 70’s with NASA Ames, Hexcel and Ciba which resulted FAA edicted standards replacing all epoxies with phenolics as specified and dictated by FAR 25.283. These programs resulted in the well known Ohio State University (OSU) and lots of Bunsen burners and research and test efforts, but only at heat fluxes in the range of 35-50 kW/m², a far cry from the present 100-200kW/m² testing demanded by fuel fed fires for all composite cf/epoxy fuselages for the new generation of all composite fuselages and wings on aircraft such as the Boeing 787 and Airbus A350XWB.

I have always maintained a high interest and involvement in FST data and its hazards since that time. For example, in a non-aerospace effort in the 80’s I was involved with offshore oil platforms concerning the Piper Alpha tragedy in North Sea via my consulting work with Nikkiso Company Ltd. and extensive visits, reviews, contacts and discussions with Conoco Phillips in the U.K.

I have also studied many accident reports re FST deaths caused by epoxy based composites over several decades. I am aware of the tragedy, but was not directly involved with FST accident reports re London Subway fires and the subsequent replacement of all epoxy interiors by other, far more FST resistant materials in London and throughout the transportation system.

Next, I note that US submarines are also closely monitored regarding epoxies, their locations and amounts due to FST hazard issues and must be very limited
for interiors and must comply with MIL l20-31 per Mr. Usman Sorathia of NSWC (Ref.1)

With the NASA/Boeing ATCAS studies, and the subsequent launch of the Boeing 787, it became clear to me that there existed the high potential for an adverse impact upon passenger and crew safety if all CF/Epoxy fuselages were to be designed, developed and placed into service without a rigorous and wide ranging program of large scale fuel fed instrumented FST tests coupled with full scale fuel fed FST tests on fractured fuselages or open passenger exits and slides to accurately assess any FST safety issues stemming from the usage of cf/epoxy throughout the fuselage, wings, and empennage on such aircraft as the Boeing 787-8 and Airbus A350XWB.

Therefore, from my perspective, forty years after the FAA edicted removal of epoxies for interiors due to unacceptable PHHR and FST hazards, then followed by the offshore and transportation industries, I believe that we have now come full circle, and now have a tightly FAA regulated interior of phenolics driven by FST demands and extensive in-service survivable crash data and an unregulated exterior of all cf/epoxy fuselage without any enforced full scale fuel fed fire testing by either the FAA and EASA governing FST.

Thus, the question clearly arises; how do the passengers both survive and then safely egress a survivable crash when the fuselage consist of combustible and flammable epoxy becomes a driving question? Further, how do Boeing and Airbus prove to the certifying authorities that passenger egress has not been adversely impacted by usage of high risk FST materials? Frankly, I do not envy Boeing engineers in their current task with the current epoxies regarding ensuring passenger safety regarding such hazards nor the certifying authorities in fulfilling their responsibilities to the traveling public.

I also strongly believe that we need certifying agencies that are both proactive and highly protective with respect to passenger safety rather than relying upon past reactive postures. Clearly, there are strong economic and corporate pressures involved, but I still insist that public policy and public safety needs demands that we openly and freely debate such risks and attempt to solve the current FST dilemma now on an expedited basis.

In the following section, I will be addressing the specific FST hazards stemming from composite fuselages constructed of high risk FST epoxies and later will review some accident reports of past survivable crash accident reports to support my thesis regarding survivable crashes, coupled with a review of survivable ruptured fuselages and, in some cases, fires resulting from such survivable crashes.

In my concluding remarks I will reiterate my opinion that passenger safety is adversely impacted in wheels up and survivable crash situations on aircraft such as the 787 and, possibly, concerning Airbus A350XWB if they choose to stay with epoxies matrices.

It does, unfortunately, seem necessary at this point, for me to directly address past and potential criticism of my position in this critical FST and associated passenger safety egress concerns. Due to some rather silly ad hominem published statements, I wish to make clear that this paper, its research, my extensive contacts and correspondence with FAA have been and only are driven by my composites experience,
technical knowledge and my work concerning FST issues. The only person paying for my research and efforts has been and is only myself.

Further, to clear the air still further, my work re potential hazards of FST for the Boeing 787 is not driven by any political agenda or any animus towards either Boeing or the Northwest Office of the FAA. The opposite is true, in fact, in that I have the highest respect for Boeing and the long proud heritage it possesses. Some of my engineering heroes and mentors were Bill Allen, Joe Sutter and, in particular, Chuck Kahler, retired Vice-President of Boeing Aircraft Wing Responsibility Center. I greatly enjoyed my three years consulting for Boeing in the late ’90s, probably a lot more than Boeing engineers enjoyed me, as my marching orders from executive management were to bring to strongest possible pressure to bear on Boeing regarding composites, their technology and its cost structure.

In an area of further concern, per Ref. 2, the FAA appears to claim that FST concerns are being addressed via Sec. 856(b) re burn through of thermal/acoustic insulation, a claim that I will dispute in this paper.

Several of my composite friends over the past few years have stated that mine is a lost cause, but I dispute that. I am not on some quixotic mission, but rather, I would merely quote a literary hero of mine, John Donne, and my own sense of engineering responsibilities and ethics, namely: “No man is an Island” and “Any man’s death diminishes me because I am involved in Mankind.” (Ref. 3).

These statements summarize the ethics of engineers and our profession in its attitude towards safety and I believe that, in taking this position, I share a common bond with Airbus and Boeing engineers and with the FAA authorities. I cite the Donne quotations to remind us that it is in all our interests as engineers to strive for the total in-service success of the 787 and the A350XWB and their successors as those aircraft will greatly expand our field and expertise. Conversely, if concerns exist, then it our clear duty to raise such concerns and that is the intent of this paper.

And I have another source to for those who admire Albert Camus. In his “The Myth of Sisyphus and Other Essays” (Ref. 4). Camus concludes that although Sisyphus is condemned forever to roll a boulder up a mountainside, and always doomed to fail, he ends his essay, as Sisyphus once more trudges down the mountain to collect his boulder, that “Sisyphus must be happy’. A thought I echo, and it helps me to continue to fight for better passenger safety standards and whilst striving to avoid any adverse FST effects concerning the new generation of predominantly composite commercial aircraft now being designed, tested and manufactured at Boeing and Airbus Industrie and other O.E.M’s.

In similar fashion, I have been privileged to freely exchange views and composites data with Mr. Mike Dostert and Dr. Larry Ilcewicz of the Northwest Office of the FAA, both of whom are clearly striving to ensure that the 787 is an advance in safety over previous aircraft. I would be less than honest if I claimed total empathy with the FAA and, from my limited perspective, my contacts and correspondence have ranged from the kind and detailed responses and understanding of Mike Dostert and Larry Ilcewicz, to my feeling rather like Pauline Collins in Shirley Valentine (1989 copyright Paramount Movies) in her talks to the wall, when expressing my concerns to some other far more hostile FAA employees. Perhaps that was my fault and approach, but it exists.
But prior to such detailed data, I wish to document the actions and requests that I have made to date in a following section, namely Section 1.4 of this paper.

1.2 Auto Ignition Fuselage Potential Fire Hazards during Wheels Up Landings or Take Off Tail Strike Incidents

Clearly, a wheel up landing or take off tail strike are both normally expected to be a fully survivable events for aluminum aircraft, however a new hazard arises for cf/epoxy fuselages during such events and that is auto ignition caused by frictional heating between fuselage and ground. I do not know the specific auto ignition temperature for Toray 3900 series epoxies as they never responded to my requests, however, but let me take an educated guess at 550-580 degrees F as the appropriate value. Boeing and Toray are invited to change and correct this estimate if they so choose, of course, but only with suitable published test data to verify any changed value. This assumed value appears later independently confirmed from a recent FAA paper which cites 300 degrees C for onset of auto ignition.

The ignition temperatures of 2024 aluminum took some digging for, but I arrived at a verifiable and reliable source, via the Journal of Physics and Chemistry, which cited an ignition temperature of around 1880 degrees F. This is well above the 980 degree F melt temperature for 2024 aluminum, but we are considering FST aspects in this paper. I note that a Boeing PR release tried to claim that the toxicity of burning aluminum alloys is worse than burning cf/epoxies, but given the 1300 degrees F lower epoxy ignition levels, I must invoke an English colloquialism from my long lost past as a response and I hereby refute the PR release as load of Cod’s Wallop (A load of nonsense in England). Boeing engineering staff came to know Cod’s Wallop well during my three year tenure at Boeing as a composites consultant in the late ‘90’s.

Again, with an epoxy fuselage, we are losing around 1300 degrees F of ignition margin and this is why I totally rejected any “equivalent to aluminum” proposition cited to me via FAA Northwest Office in mid 2006. My other primary grounds clearly involve the FST hazards as I am now citing and that been clearly and widely documented over the past decades.

The quoted M.T.O.W. by Boeing and Flight International for the 787 series aircraft under review is currently in area of 484K# for the baseline -8 and 540K# for the -9 aircraft and it is reasonable, at least to this writer, to assume max. landing weight would be approximately 75% of MTOW, yielding a landing weight range of 363K# for -8 to 405 K# for the -9 aircraft. Landing speed is estimated by the author as around 120 knots. However, I note that in a recent A340 separately cited and reviewed in this papers, speeds were far higher and listed at around 170 knots by the Australian AAIB. This total energy must be primarily dissipated via friction which in turn leads to frictional heating, of course.

I further note that I have seen no published data from Boeing concerning auto ignition and wheels up landing generated friction induced fires and attendant FST hazards to date, nor have the FAA issued a Special Condition specifically requiring Boeing to perform and verify such a wheels up test. Of course, Boeing could have performed such a large scale test and I note that in my formal comments to FAA, I requested a forward suitable landing velocity vector to properly assess and simulate such a wheels up landing
or tail strike incident to be included in their crash worthiness Special Condition test, but that request, as is true of all my requests to FAA re FST hazards, was rejected.

And, finally, for any of those in the community who are comfortable with no simulated wheel up test I would cite a series of excellent and recent published German research sources wherein EADS and Airbus have been and are investigating a series and longitudinal shock absorbers and plates to alleviate and minimize frictional and auto ignition effects (Ref. 5, 6, 7 and 8) so clearly Airbus and EADS have serious concerns concerned in this area of FST and passenger safety re crash worthiness and passenger FST protection.

1-3 An Assessment of the Approaches Employed by Boeing and Airbus concerning Material Selection and Testing and Publications

In my view of things, Boeing reversed the normal aerospace practice of assessing and testing a wide range of options prior to settling on a final material selection for the 787. EADS and Airbus are clearly following the traditional route as cited above, so they are excluded from this immediate discussion. In the case of Boeing, however, Toray was and is the sole source supplier for primary structures for 777 under BMS8-276. When 787 started development, again Toray is the only supplier for the primary structure with their 3900 series epoxy, situation that creates a myriad of difficulties for Boeing’s design structural and FST engineers concerning FST and associated passenger safety issues.

If you have a pre-selected material and only one material at that and a flammable and combustible one at that with known high FST risks, this is a very difficult situation for the Boeing engineers. Engineers like to test, assess, and try different materials prior to arriving at a consensus of the best material to employ for a given range of applications. In this case, at Boeing, there was no choice and this is why I stated earlier that I do not envy the many excellent Boeing engineers on this program or their many supply chain partners who were placed in the same boat. Also there has been and remains a dearth of published papers concerning FST testing and results regarding the 787-8 FST full scale and development and component tests from Boeing, which is deemed most unfortunate for those of us in the composites community with a strong and ongoing interest in this critical subject. Rather, Boeing seems, at least to this engineer, to be relying on PR and Communications Office statements to the press and a seeming corporate imposed ban on open debate for their skilled composite engineers with their outside peers. That is Boeing’s choice and if that is their Executive Corporate policy, then so be it, but I do not believe that it serves Boeing well. I think that such a policy is misguided and hope that Boeing soon reverses its present position and clearly addresses FST from its engineering staff. I have found some outlines and briefs from FAA concerning development of new burners in support of testing lower insulated fuselages in support of 25.856(b), such as Mr. Gardlin’s and the FAA’s outline summary entitled “Future Advisory Material 25.856(b) from a International Aircraft Fire Test Working Group (IAMFTWG) meeting at Cuyhoga Falls, dated March 6th 2007, but such materials are very short on specifics and only states as a conclusion:

“Internal Coordination in progress”
Out for Public Comment this Summer (2007)"

In mid-December 2007, for example, I tried to initiate informal engineer to engineer exchange with a key Boeing engineer through a third party, but he had to decline citing that only Corporate Communications could talk regarding such FST tests. This muzzling of engineers approach with respect to Boeing 787-8 serves no useful purpose in my mind, but rather results in adverse effects for our aerospace industry which has traditionally relied upon the free give and take and open ideas for non-classified commercial applications.

In contrast to Boeing and their present, as I view it, their Corporate and P.R. controlled approach to the potential composite fuselage FST problems, EADS and Airbus are to be praised and they have published a series of well documented papers and presentations concerning potential composite usage and design approaches. Examples of such published research and innovative and creative design thinking are presented in Ref (5), (6), (7) and (8) and I urge SAMPE Journal readers obtain copies of such papers for their own review as they are available on-line.

I also note that, very wisely, in this engineer’s opinion that EADS and Airbus appear to be actively exploring non-epoxy options, for which I applaud them and hope that their development window allows a safer non-epoxy solution to be tested, developed and qualified. So, given the state of flux re A350XWB materials at present, clearly the main focus in this paper primarily involves the Boeing 787 given its pending certification status and target EIS.

1-4. Prior contacts, correspondence, submittals and requests re potential FST epoxy composite fuselage hazards

As a result of my existing FST knowledge and strong concerns, I contacted the FAA in middle of 2006 and was told that Northwest FAA office was thinking in terms of “equivalent to aluminum”, a claim I refuted in some detail via E-mail, but that particular line of correspondence then ceased. I then researched and found Dr. Mouritz’ S superb RMIT Australian paper: “Fire Safety of Advanced Composites for Aircraft” published in April 2006 and funded by Australian Transport Safety Board.” (Ref. 9). I ensured that copies of this paper reached Boeing and received a polite “thank you and very interesting” type reply, but nothing more. I did further work and was very depressed to find that whereas rigorous regulations FAA existed for aircraft interiors, as cited above, no, repeat no regulations existed for exterior composite fires and FST. Clearly this is a major loophole which I believe must be quickly addressed by FAA and all other certifying authorities such as EASA and CAA.

Next I contacted the FAA Northwest office and was informed that there were a pending series of Special Conditions in preparation and a volley of nine of such Special Conditions were issued in the first quarter of 2007 and can be found at http://rgl.faa.gov (please enter as a search term 787-8 for your reference). Some of these were non-applicable to the FST hazard discussion at hand, but three or so were and I
responded with my concerns in formal comments as requested. My concerns were noted, agreed with, but my suggestion for large scale and full scale fuel fed FST tests were not acted upon nor was my request for a forward velocity vector to be included in the Arizona crash-worthiness test, which request was based upon the autoignition wheels up landing FST concern cited above. All these requests were totally rejected by FAA who consistently cited various combinations of “the FAA agrees that the FST concerns of the commentator are of high concern” coupled with, unfortunately that hoary old bureaucratic excuse of “out of scope”. I also suggested a new FST based Special Condition, but was again rejected. Fortunately I was referred to Dr. Larry Ilcewitz as their composites expert by Mr. Mike Dostert and he was most responsive as had been Mr. Dostert in several conversations and communications earlier.

I will be discussing the 787 and A350 CF/epoxy FST hazard in depth in the next section concerning published FST papers from series of highly qualified sources. After their review, I hope that I can convince some or a majority of my SAMPE readers that my concerns regarding potential FST hazards stemming from the use of an all cf/epoxy fuselage are valid and worthy of further study and composites community debate.

I must further note, for historical completeness and clarification purposes, that after I submitted my formal written comments to the FAA, I was contacted by Mr. Vince Weldon via phone as the FAA evidently gave him my address and phone data; He clearly has or had personal issues concerning Boeing, which I certainly do not and he was focusing only on crash-worthiness not FST or differential CTE matters.

I must repeat again that I harbor no animus against Boeing whatsoever and greatly enjoyed my three year composites consulting effort with them in the late 90’s. I greatly admire them as a company and the quality and dedication and skills of their engineers, just as I do Airbus, who has equally superb engineers, leaders and a long aerospace and composites heritage. But let us always remember the adage “We engineers make mistakes and that is why we have erasers on our pencils”. Mistakes can and do happen I have made plenty in my time, and I appeal for open minds and honest and open debate after I finish this paper. I also have no quarrel with Mr. Weldon, but we are clearly on different tracks regarding the 787 aircraft.

Mr. Weldon had not previously recognized the FST problem and major potential hazards that I believe exist, but wanted me “on his team” to attack FAA and Boeing. This was rejected by me and after one more phone call attempt by him and again another point blank refusal from me, I never heard from Mr. Weldon again. I did, however, subsequently have phone calls from Dan Rather’s reporters on two occasions soliciting my participation to the Rather/ Weldon TV documentary as Mr. Weldon was working with Mr. Rather’s TV team. They, in turn, were rejected and I told them that I was only interested in working via FAA as the responsible certifying agency for 787 and EASA for A350XWB and Boeing and Airbus engineers and via SAMPE Journal articles and suitable peer review and rational engineering and fire safety experts discussions and debate. I watched the resulting program and was impressed by some citations and comments, but clearly there were errors and I am not convinced concerning the program’s accusations of corruption or collusion.

Clearly, the last thing I want for the FAA or Boeing or our industry is a future incident of a survivable crash or wheels up landing occurring, as it will inevitably
happen, and for passengers to die needlessly if we evade the FST issue now and for a subsequent NTSB report to emerge excoriating Boeing, Airbus, FAA and EASA for failures in certification standards or lack of suitable FST full scale testing at either of the two key Emerson’ involved in the design and development of the 787 and A350XWB.

I have, during my career, lived through many aircraft issues and crash incidents starting as a young apprentice at De Havillands with the early Comet crashes, the Airspeed Ambassador runway slush induced crash in Germany due to icing, the hydrogen embrittlement issues in early maraging 4340 steels, early 7075-T6 short transverse material problems, the Lockheed Electra flutter problem and crashes, the deep stall problems of the BAe 111 and associated fixes to the DC-9 and the F-111 D6AC wing pivot problems in Vietnam war crashes due to “pivot fitting material defects being below detectable inspection standards”. These in-service problems led the USAF to rightly edict a proof load test program of all F-111 wings and empennages, which were expensive as an understatement. In addition the Boeing 737 rudder problem crashes, the Boeing 767 Thai crash and the Airbus AA 587 New York crash can be cited.

As an engineer, each crash or series of crashes leaves its mark and memory and I want the highest standard of safety to be ensured for both Boeing 787 and Airbus A350XWB in service as, I am sure, do the engineers of both these fine companies.

However, first, the onus is upon me to attempt to prove my position re a major potential FST hazard concerning cf/epoxy composite fuselages on the present 787aircraft series and possibly for the A350XWB aircraft depending upon their final design configuration and material selection. This I intend to accomplish via a selected series of FST focus papers and reports concerning epoxy matrix composites.

Section 2  A Review of some published FST epoxy hazard papers

2.1.1 Dr. Adrian P. Mouritz  report for the Australian Transportation Safety Bureau (April 2006) (ref. 9)

This section presents the body of evidence published or in my possession on which my high FST concerns for 787 epoxy fuselages and wings are based. Clearly the literature over the past decades is replete with such evidence, but I have chosen to select a limited set of four sources to cite and illustrate in this paper and they, in turn, provide ample references for further research by interested and involved individuals. In this paper, I will cite Dr. A.P. Mouritz’s outstanding paper (Ref. 9), supported by NASA Studies (Ref. 11), FAA reports (Ref. 10) and finally an EADS sponsored study and report regarding the Luof2 program in support of the Airbus A350XWB program (Ref. 12).

First, I will cite and quote some extracts from Dr. A. P. Mouritz’s 2006 Australian ATSB Study “Fire Safety of Advanced Composites for Aircraft” Aviation Safety Research Grant-B2004/0046 published in April 2006. (Ref. 9). I have also been in touch with Professor Mouritz and he has kindly given me other inputs via private correspondence, for example stating “that full scale FST fuselage testing is critical and that OSU and sample tests are insufficient” in his private correspondence to me.

I think it appropriate and germane to quote one of his key findings, namely:
“The composite most often used in pressurized aircraft cabins is glass/phenolics, and the database shows that this material has excellent fire reaction performance and that very few next-generation composites display superior properties. The most used structural composite is carbon/epoxy, and this material has poor fire resistance and can pose a serious fire hazard.”

The utility of Dr. Mouritz’s report is that he summarizes accident report and FST incidents as well as generating and presenting a wide-ranging database covering most thermosets and thermoplastics and that his extensive report is presented in a highly logical and totally comprehensive manner.

Now I would also note the his paper is also somewhat limited in terms of time to ignition and other FST dominated properties in discussing fuel fed external composite fuselage fires which involve heat fluxes in the 100-200 kW/m² range, whereas Dr. Mouritz’s heat flux level and database are limited to a far lower interior in-flight cabin fire level at 50 kW/m². However, as he notes, although absolute times and values will certainly change at higher heat fluxes, the relative ranking will remain constant and he clearly states this key point early in his report:

“The time–to-ignition values were measured using the cone calorimeter technique (ASTM D1354) at an incident heat flux of 50 kW/m².” And that with respect to peak heat release rate (PHRR) that the FAA require the PHRR to be measured using the Ohio State University (OSU) calorimeter operating at a heat flux of 35kW/m². Data from cone calorimeter testing is presented because a much larger number of PHRR results are available using this technique. It is expected that the order of ranking given in the tables would be similar were the OSU calorimeter used for the measurements.”

Again, I do not plan to present all of Dr. Mouritz’s many findings listed in his extensive database, but rather I will be offering a selection which are believe are of key interest to our current situation and intend to bolster and cite other sources to support my case.

Next let us review Dr. Mouritz’s report introduction, namely:

“Fire is a major safety hazard for civil, commercial and military aircraft. In-flight fire is ranked as the fourth highest contributing cause of fatalities arising from accidents involving commercial jet aircraft. The FAA believes that if aircraft accident rates continue at a constant rate, then death due to fire will increase at 4% per annum in-line with growth in air passenger traffic.

Without careful management and strict safety regulations, the risk of aircraft fires could increase with growing use of fiber reinforced polymer composite materials in aircraft. Many polymer composites rapidly ignite when exposed to fire and generate high amounts of heat, blinding smoke and choking fumes. The careful selection of fire resistant composite materials is essential to aircraft safety.”
Now, please contrast these expert statements with no current existing FAA regulations, to my knowledge, for external composite fires and the blanket denial that FST poses any hazard on Boeing 787 by Boeing (Ref. 10), the contrast is stark and telling.

Continuing with Dr. Mouritz’s report he cites aircraft composites usage at around 5-10% up to 777. However, the Boeing 787 is over 50% composite (and cf/ epoxy at that) and similar levels are quoted for Airbus A350XWB and clearly this is a very sharp and significant increase in both usage and in terms of potential FST fuselage fire hazards.

Now again quoting from the Mouritz report (page 3):

“Carbon reinforced epoxy composites are used in aircraft structures including fuselage, wing and tail fin components, control surfaces and doors…………Most types of carbon/epoxy laminates used in aircraft structures are flammable and readily decompose when exposed to heat and fire.

Fire retardant epoxies and other fire-resistant polymers are being used increasingly in carbon fiber composite aircraft structures; however these materials are often more expensive and may not have the same mechanical performance as conventional aerospace grade epoxies.”

Now I know that various additives such as phosphorus and other flame retardant “angel dust” as it is known to the chemists of this world have been, and are being tried, but these have no been proved to be successful per the EADS data as will be cited and discussed later in this section.

In extracting data from the Mouritz report, I have taken the liberty of focusing upon epoxies of several varieties, phenolics, PEEK and cyanate esters as these, I believe, represent the range of responses to FST testing and probably encompass the range of possibly viable materials for commercial aircraft primary composite structure usage, but the reader is invited to review all aspects of the Mouritz report which is available on-line. Dr. Mouritz’s tables are included in full, but the cited materials are marked with asterisks for your reference.

Dr. Mouritz in his report cites a wide-ranging number of applicable FST research paper references for those interested in pursuing further research. I will not examine the totality of FST tests cited by Dr. Mouritz, but will limit my figures to those pertaining to some critical FST issues, namely: PHRR (Peak Heat Release Rate), Average HRR, Total HRR, Flame Spread Rate and Smoke Specific Extinction Area (SEA). These Mouritz report results are listed in figures 2, 3, 4, and 5 on the following pages, however, I would first cite the following key results based upon this data:

1. For PHRR, epoxies ranks as one of the worst materials and depending upon formulation cyanate esters
2. For Average HRR rate, a critical property, carbon epoxies has one of the highest average HRR of the thirteen materials tested
3. For total HRR, the geothermal and several thermoplastic composites possess heat release values much lower than carbon/epoxy
4. For Flame Spread Rate, clearly epoxies are inferior to PEEK and phenolics
5. For Smoke (SEA) again, clearly epoxies rank amongst the worst of all materials tested.

In summary, the Dr. Mouritz report is a damning indictment of cf/epoxies with respect to FST hazards concerning aircraft composite structures. Dr. Mouritz also warns that “a composite material can release a large number of different types of gases including; carbon monoxide, carbon dioxide, tolene, methane, acetone, HCL, and HCN plus many other toxic gases” and adds that: “Most studies of the combustion gases released by burning composite materials **focus only on carbon monoxide and carbon dioxide, and ignore other gases despite their potential hazards**”. The author knows of some HCN problems arising with some second and third generation toughened epoxies, but again lacks any specific Toray 3900 series information, leaving that potential hazard hanging for the present and awaiting further data and clarification from Toray, Boeing and FAA. Cyanate esters have also been accused of high HCN release during combustion and that issue is discussed later in this section regarding the EADS and Airbus FST research results.
### Performance table for peak heat release rate values for structural composite materials. (All materials reinforced with carbon fibres unless otherwise indicated).

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Polymer matrix</th>
<th>PHRR (kw/m²)</th>
<th>Improvement factor</th>
<th>Reference source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Geopolymer</td>
<td>0</td>
<td>Infinity</td>
<td>Lyon et al. (1997)</td>
</tr>
<tr>
<td>2</td>
<td>PES (polyoethersulfone)</td>
<td>11</td>
<td>21.8</td>
<td>Lyon et al. (1997)</td>
</tr>
<tr>
<td>3</td>
<td>PEEK (polyetheretherketone)</td>
<td>14</td>
<td>17.1</td>
<td>Lyon et al. (1997)</td>
</tr>
<tr>
<td>4</td>
<td>PEKK (polyetherketoneketone)</td>
<td>21</td>
<td>11.4</td>
<td>Lyon et al. (1997)</td>
</tr>
<tr>
<td>5</td>
<td>Polysulfone</td>
<td>24</td>
<td>10.0</td>
<td>Lyon et al. (1997)</td>
</tr>
<tr>
<td>6</td>
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<td>37</td>
<td>8.5</td>
<td>Sorathi et al. (1994)</td>
</tr>
<tr>
<td>7</td>
<td>Phenolic</td>
<td>48</td>
<td>5.0</td>
<td>Hsieh &amp; Beeson (1997)</td>
</tr>
<tr>
<td>8</td>
<td>Phthalonitrile</td>
<td>55</td>
<td>4.4</td>
<td>Koo et al. (2000)</td>
</tr>
<tr>
<td>9</td>
<td>Phenolic*</td>
<td>85</td>
<td>2.8</td>
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<td>89</td>
<td>2.7</td>
<td>Brown et al. (1994)</td>
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<td>Phenolic*</td>
<td>98</td>
<td>2.4</td>
<td>Sorathi et al. (1994)</td>
</tr>
<tr>
<td>12</td>
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<td>163</td>
<td>1.5</td>
<td>Sorathi et al. (1994)</td>
</tr>
<tr>
<td>13</td>
<td>Epoxy</td>
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<td>1.4</td>
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</tr>
<tr>
<td>14</td>
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<td>184</td>
<td>1.3</td>
<td>Brown et al. (1994)</td>
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<td>15</td>
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<td>186</td>
<td>1.3</td>
<td>Brown et al. (1994)</td>
</tr>
<tr>
<td>16</td>
<td>Epoxy*</td>
<td>207</td>
<td>1.2</td>
<td>Brown et al. (1994)</td>
</tr>
<tr>
<td>17</td>
<td>Epoxy</td>
<td>240 ± 24</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
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<td>608</td>
<td>0.4</td>
<td>Brown et al. (1994)</td>
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<tr>
<td>19</td>
<td>Vinyl ester*</td>
<td>812</td>
<td>0.3</td>
<td>Brown et al. (1994)</td>
</tr>
</tbody>
</table>

* Aramid fibre reinforcement  
# Polyethylene fibre reinforcement  
The time-to-ignition values were measured using the cone calorimeter technique (ASTM D1354) at an incident heat flux of 50 kW/m².

### Performance table for average heat release rate values for structural composite materials. (All materials reinforced with carbon fibres unless otherwise indicated).

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Polymer matrix</th>
<th>Average heat release rate (kcal/m²)</th>
<th>Improvement factor</th>
<th>Reference resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Geopolymer</td>
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<td>Infinity</td>
<td>Lyon et al. (1997)</td>
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<td>2</td>
<td>PES (polyoethersulfone)</td>
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<td>Lyon et al. (1997)</td>
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<td>3</td>
<td>PEEK (polyetheretherketone)</td>
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<td>17.4</td>
<td>Lyon et al. (1997)</td>
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<td>1.8</td>
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<td>97</td>
<td>1.4</td>
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</tr>
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<td>8</td>
<td>Bismaleimide</td>
<td>110</td>
<td>1.3</td>
<td>Brown (1987)</td>
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<tr>
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<td>Vinyl ester*</td>
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<td>Brown et al. (1994)</td>
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<td>Vinyl ester*</td>
<td>350</td>
<td>0.4</td>
<td>Brown et al. (1994)</td>
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</tbody>
</table>

* Aramid fibre reinforcement  
# Polyethylene fibre reinforcement  
The time-to-ignition values were measured using the cone calorimeter technique (ASTM D1354) at an incident heat flux of 50 kW/m².
### Performance table for flame spread index rate values for structural composite materials.

<table>
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<th>Ranking</th>
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<th>Improvement factor</th>
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<td>PPS (polyphenylenesulfide)</td>
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<td>1.57</td>
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<td>8</td>
<td>1.38</td>
<td>Sorathia et al. (1994)</td>
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<td>Phenolic</td>
<td>48</td>
<td>0.23</td>
<td>Sorathia et al. (1994)</td>
</tr>
</tbody>
</table>

* Aramid fibre reinforcement
# Polyethylene fibre reinforcement
The flame spread rate index values were measured according to ASTM E162.

---

### Performance table for smoke specific extinction area (SEA) values for structural composite materials.

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Polymer matrix</th>
<th>SEA (m²/kg)</th>
<th>Improvement factor</th>
<th>Reference source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Geopolymer</td>
<td>0</td>
<td>Infinity</td>
<td>Lyon et al. (1977)</td>
</tr>
<tr>
<td>2</td>
<td>PEEK (polyetheretherketone)</td>
<td>69</td>
<td>17.9</td>
<td>Lyon et al. (1977)</td>
</tr>
<tr>
<td>3</td>
<td>PES (polyethersulfone)</td>
<td>145</td>
<td>8.5</td>
<td>Lyon et al. (1977)</td>
</tr>
<tr>
<td>4</td>
<td>Phenolic</td>
<td>166</td>
<td>7.9</td>
<td>Sorathia et al. (1994)</td>
</tr>
<tr>
<td>5</td>
<td>PEKK(polyetherketoneketone)</td>
<td>274</td>
<td>4.5</td>
<td>Lyon et al. (1977)</td>
</tr>
<tr>
<td>6</td>
<td>Phenolic</td>
<td>294</td>
<td>4.2</td>
<td>Sorathia et al. (1994)</td>
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<td>7</td>
<td>Phenolic</td>
<td>403</td>
<td>3.1</td>
<td>Brown et al. (1994)</td>
</tr>
<tr>
<td>8</td>
<td>Phenolic</td>
<td>589</td>
<td>2.1</td>
<td>Brown et al. (1994)</td>
</tr>
<tr>
<td>9</td>
<td>Vinyl ester</td>
<td>792</td>
<td>1.6</td>
<td>Brown et al. (1994)</td>
</tr>
<tr>
<td>10</td>
<td>Epoxy</td>
<td>808</td>
<td>1.5</td>
<td>Brown et al. (1994)</td>
</tr>
<tr>
<td>11</td>
<td>Epoxy</td>
<td>860</td>
<td>1.4</td>
<td>Brown et al. (1994)</td>
</tr>
<tr>
<td>12</td>
<td>Vinyl ester</td>
<td>888</td>
<td>1.4</td>
<td>Brown et al. (1994)</td>
</tr>
<tr>
<td>13</td>
<td>Epoxy</td>
<td>1232</td>
<td>1.0</td>
<td>Mouritz (2005)</td>
</tr>
</tbody>
</table>

* Aramid fibre reinforcement
# Polyethylene fibre reinforcement
The time-to-ignition values were measured using the cone calorimeter technique (ASTM D1354) at an incident heat flux of 50 kW/m².
2.1.2 Health Hazards of Combustion Products From Aircraft Composite Materials“ Authored by Dr. Sanjeev Gandhi and Dr. Richard E. Lyon (ref. 10)

This report was published in September 1998, so is of recent vintage and both Dr. Gandhi and Dr. Lyon are widely known and respected researchers in the FST field. Additionally, this report was published under the aegis of DOT and FAA and is noteworthy for its extensive bibliography and references which will aid further research. Clearly this paper is primarily focused upon post fire fiber and health issues, but a number of salient facts emerge and there clearly also exists a potential hazard for fire-fighting crews for the new generation of composite fuselage and winged aircraft in addition to major potential hazards concerning the passengers and crew during survivable crashes. The report extensively reviews the results of large scale fire tests both at Naval Weapon Center (NWC) at China Lake, CA and at the U.S. Army’s Dugway Proving Ground in Utah. The NWC tests in California tested actual aircraft composite parts, as discussed on page 12 of the report states that “specifically an F-16 fighter fuselage section and a Boeing 737 spoiler to flames for 4-6 minutes” (my emphasis added). The resulting attempted collection of samples re fibers released was rendered highly difficult “as the massive smoke plume that reached a height of ~1000 m carried the majority of the single fibers away from the test location to distances beyond the instrumentation limit of 2000 m” (again my emphasis added).

The author of this current paper believes that such test results on a small military aircraft section and a very small aircraft composite part should give great pause to any reader in reviewing and contemplating the potential FST and fire hazards for large, new generation aircraft such as the Boeing 787 series.

In addition, nothing in this report conflicts with Dr. Mouritz’s report examined previously, nor does it conflict with later excellent 2003 EADS and Airbus presentations and reports concerning fuselage burn-through and testing of various toughened epoxies and PEEK together with PT-15 a cyanate ester (specifically the phenolics backbones phenolics triazine material originally developed by Allied-Signal). This interesting PT-15 material has been extensively tested, reformulated and modified by Lorsa, Switzerland, Steselit AG, Switzerland and Gurit (Zullwil) AG to ensure high temperature performance with excellent resistance to FST hazards. This material is examined and discussed later in this section and is already qualified for high temperature air ducting per BMS8-363 at Boeing Seattle and per DMS2441, DMS2296 and DMS2297, so is scarcely a pipe-dream or long term research project.

First, I would quote the abstract of the DOT/FAA report cited above:

“Concerns about the potential health hazards of burning fiber-reinforced polymer composites in aircraft fires parallel the rising usage of these materials for commercial aircraft primary and secondary structures. An overview of the nature and the potential hazards associated with airborne carbon fibers released during flaming combustion is presented. The current data derived from animal studies are insufficient to determine the acute toxicity of carbon fibers
from burning composites. Further work is needed to examine the adverse health effects of volatile organic chemicals and to assess if any synergistic interactions exist with the fibers”.

Obviously, over the past decades there have been many military FST crashes and fire-fighting and health issues have arisen, but none on the scale of large Commercial Aircraft carrying passengers and crew in excess of 300.

Next I would like to quote from Pages 4 and 5 of the DOT/FAA report:

“Epoxy resins are the most common thermoset resins in commercial aircraft applications because they are relatively tough, easy to process, and have moderate temperature capability. Unfortunately epoxies are very flammable and cannot be used as matrix materials in composites for aircraft interiors that must pass strict heat release regulations. Phenolics are the thermoset resin of choice for aircraft interiors solely because of their low heat release rate”

Thus again, and from an excellent source we have epoxies cited for high flammability and high HRR. I hope a pattern of evidence is beginning to emerge for my reader.

Later, in the same report, in the conclusions on Page 16, I would again quote:

“Structural applications for fiber-reinforced polymer composites in commercial transport aircraft structures have increased significantly over the past decade (**note that this was written in 1998 before the almost totally cf/epoxy 787 was developed) and will continue to grow in next generation aircraft. The primary fire hazard of interior and secondary composites used in aircraft cabin and fuselage components is the high release rate (HRR) and the toxicity of the gaseous combustion products from the burning polymer matrix. The aircraft cabin occupants are exposed to this hazard during an impact-survivable crash”.

The above statement totally echoes my position re major FST hazards concerning commercial aircraft cf/epoxy fuselages and I very pleased that it is in an FAA sponsored report.

2.1.3 “Fire and Smoke-Resistant Interior Materials for Commercial Transport Aircraft, National Materials Advisory Board, National Research Council, dated 1995 (ref. 11)

The cited report is long and detailed, just as, I must freely confess, is the present paper, but, given the potential major hazards involved, I believe that nothing less than a fully detailed extensively researched and accurately cited paper can do justice to this vital subject of public policy. Dr. Eli M. Pearce was the Chair of the Committee and visits to FAA, Airbus and Boeing were involved in its preparation.

The clear focus of the report is on interiors, but a number of salient facts emerge, Further, this report is most useful for its discussion of annual accident rates,
fatal accident rates and fatalities plus an excellent summary of in-flight and on-ground
smoke and accidents. I do not propose to list all the extensive figures and tables contained
in the report, but will choose a few considered most relevant to the subject of this paper.
The report specifically cites the Aviation Safety Research Act of 1988 (Public Law 100-
591) which provides the FAA with a mandate to conduct long term investigations
concerned with fire safety, including fire containment and the fire resistance of cabin
materials. The long term goal is set at “achieving totally fire resistant interiors on future
aircraft”. It also discusses the FAA long term goal of achieving an “order of magnitude”
improvement in fire resistance and discusses the problems involved. However,
juxtaposing the 1988 Act against the evidence of severe FST potential hazards
concerning cf/epoxy hazards re 787 and potentially A350XWB aircraft, makes for
sobering reading.

Clearly if the papers and reports cited above are true, then major
questions arise concerning any improvements regarding passenger safety and egress with
respect to the new generation of commercial transports epitomized by the Boeing 787.

To quote from Pg. 3 of the report:

“Based on prior experience, two basic aircraft fire scenarios have been
identified: post-crash fires involving (potentially large) quantities of aviation fuel
from ruptured fuel tanks and in-flight fires involving only interior cabin
components and passenger-specific items”. And follows by stating: “However, new
aircraft configurations may be significantly different from past designs, and the
response of aircraft interiors in these fire scenarios depends upon the details of the
design. Thus each aircraft configuration must be analyzed to assess its response”.

I would take these remarks considerably further and cite that the both the
787 and a350XWB aircraft involve at least a quadrupling, and possibly a quintupling, of
composites usage over previous aircraft such as the A340 series and the 777. This
unprecedented jump in composite usage now clearly involves surrounding the
passengers’ compartment, for example, with **proven flammable, high smoke
generating, toxic fume producing and combustible cf/epoxy materials** for the 787,
which represents a quantum jump both in usage and in areas of application and for the
writer, introduce greatly heightened FST risk for the first time. Hence, in my opinion, it is
critical that sufficient and full scale FST testing be demanded, not just encouraged, on
full scale ruptured sections of such commercial aircraft by the applicants prior to, and as a
condition of, formal FAA and EASA certification. Sadly this is not the position of the
certifying authorities at this juncture, which has led to my extensive research over the
past two years, coupled with both formal and informal contacts with these agencies and
ultimately has resulted in the preparation of this paper.

Returning to the subject report and quoting from page 7 of the report

“From 1953 through 1993, there were 398 fatal accidents with 19,298
fatalities, of which 319 accidents and 18,956 fatalities were in passenger aircraft. In
the ten year period 1984-93 there were 120 fatal accidents with 5,526 fatalities, of
which 96 accidents and 5,397 were in passenger aircraft”.
So the author wishes to clearly state that we are not talking small numbers, but rather many thousands of passengers and it is clear that the vast bulk of injuries and fatalities occur in commercial aircraft.

I also wish to cite, in fairness to all the many companies and agencies concerned, the past and ongoing efforts of agencies such as FAA, EASA, CAA, and the NTSB combined with the ongoing efforts of commercial aircraft manufacturers in improving accident rates based upon flight departures. Specific improvements in ATC, Terrain Avoidance and C.A.T. instrumentation, vastly improved radar systems and airline engineering, maintenance and crew training has also greatly contributed to safety. In addition, aircraft design standards, materials testing and research and engine software have all paid their part. Next, I recognize and welcome Boeing’s decision to introduce nitrogen inverting fuel systems on the 787 as previously used in military aircraft, just as I welcome and support the efforts of FAA re improved thermal insulation and burn-through barriers per FAR Sec. 25.256(b). Such research and improvements, however, must continue unceasingly and must not be limited to solely, sometimes superficial or tendentious cost benefit analyses, nor to overstate implementation does costs or weight impact either. There always design and cost limits, I fully recognize, but passenger safety must stay central to our thinking and decisions.

Additionally, however, we must be also be extremely careful not to introduce new potential FST hazards in the new generation of commercial aircraft as is the focus of this paper. Also, I note that NTSB cites with great concern that each year 125 runway incursion incidents occur with at least 25 deemed as critical to safety. So we are operating in a highly hazardous and critical area as departures increase at an over 3% rate, airports become more crowded, new and far-flung, inexperienced, low cost airlines come in operation and ATC overload grows ever higher. Hence we, the O.E.M.s and their engineers and all certifying and safety agencies must be highly pro-active not reactive in this area at all times. Engineers know this well and with their ethos and sense of responsibility should and must force them to be ever vigilant and strive to minimize the infamous “unk-unks’ which often bedevil our chosen aviation composite profession.

Returning to the current FST report under discussion, I wish to make one final quotation from page 24 of that report, namely:

“Post-Crash External Fuel Fires

The FAA Technical Center has developed criteria for the current generation of improved (my note, presumably phenolics and other FST resistant materials), fire-resistant cabin materials based on the characterization of the fire environment through a series of full-scale fire tests (Sarkos ref, 1995). The scenario that has been emphasized in the FAA tests has been the post-crash fuel-fed fires with the fuselage largely intact. Post-crash scenarios have been the focus of FAA work because all accidental fire-related fatalities in the United States in the past 30 years have been due to post-crash fires (Sarkos, 1995; Murray, 1995). (my emphasis added). Although other scenarios must be considered, a largely intact fuselage (with openings for fire and smoke to enter (my emphasis added) has been emphasized by the FAA because (1) the impact fuselage would be more likely to be an impact survivable crash, and (2) direct entry
of flames provides the quickest ignition for interior furnishings (Sarkos and Hill, 1989).”

Next on the same page and directly related to the above quotation in describing the two different scenarios envisioned the subject report states as follows:

1. **One or more holes in the fuselage; only flame radiation enters.** In this scenario, ignition of interior is by radiation (no flames) and fire growth is typical of an enclosure fire. The important characteristics include piloted ignition, fire plumes, radiation interactions and flash-over. Fuels for the enclosure fire include interior components and passenger personal items such as clothing and carry-on items.

2. **One or more holes (door or rupture) in the fuselage; flames and smoke enter:** In this case, the upper layer of the fuselage is quickly vitiated, and thus the thermal decomposition of the exposed panels is different. Internal ignition is by direct flame contact near fuselage openings. If an escape door (down wind is opened, the external flames may extend along the fuselage ceiling and seriously disrupt escape.”

Now, stepping away from the National Materials Advisory Board report under review for a moment, all the following statements being clearly prefaced with, to the best of my knowledge and to date, as I do not know all the relevant FST testing and its results conducted by Boeing, but let me cite my current view of what has happened and is happening with respect to cf/epoxy fuselages for the Boeing 787 during my studies over the past two years:

1. Informal correspondence with FAA has confirmed to me that, to date, no large scale tests have taken place to date involving cf/epoxy 787 type composite fuselages have taken place at the FAA Technical Center to date.

2. All emphasis by Boeing and by FAA fuselage group appears to be only focused on new burn-through specimen tests per the latest FAR Sec. 25.256(b).

3. The latest FAR Sec. 25.256(b), cited in detail below contains no reference to ruptured fuselage testing and is focused only on improved thermal and insulation requirements (praiseworthy though that is), but this improvement is only applicable for the lower half of the fuselage at that, thereby potentially exposing to future risk cartwheel landings as have proved survivable in the past for large commercial metallic fuselage airplanes as I will discuss and review in Section 4.

4. All my formal written and informal comments and requests for ruptured fuselage FST full scale tests or tests with open doors and exits to the FAA have been rejected (I commented specifically on three of the 2006 FAA Special Conditions as is cited below) with claims of “out of scope”
and the FAA, as a further basis for rejection, used the latest FAR Sec. 25.256(b) document.

5. I have found no published papers or presentations in the open literature from Boeing reporting on any fuel-fed full scale cf/composite fuselage FST tests for 787 for ruptured or penetrated or exit doors open and slides deployed.

6. In private correspondence, the FAA has stated to me “That there are rumors of large scale FST tests being conducted at Boeing”, but “Boeing may not yet be ready to share results with FAA and the composites community”

7. The FAA in their final versions of the Special Conditions in question stated that the basis of 787 certification will be “per an equivalent level of safety approach” which is negotiated and settled directly between Boeing the FAA without any outside public inputs allowed. I note that, at the time of writing of this paper (late December 2007) that no such equivalent level of safety finding has been published on the FAA web site, namely http://rgl.faa.gov.

8. In the latest Boeing Webcast re 787 held on December 11 2007, Mr. Scott Carson stated that “all certification technical requirements for the 787 aircraft had been settled upon between the FAA and Boeing’ and proudly noted that “this agreement re technical requirements for 787 certification was the earliest ever achieved”.

I think the reader will clearly discern a pattern here and what appears to be a reversal of the previous National Materials Advisory Board statements cited above concerning full scale fuselage penetration and rupture FST tests at the FAA Technical Center. This is why I am writing this paper as clearly, at least in my mind, a major potential FST hazard exists for the new generation all cf/epoxy fuselages currently undergoing certification review by the FAA, EASA, CAA and other responsible agencies per the Mouritz and Gandhi and Lyon papers reviewed earlier and no published papers cite any results refuting this concern at this point from such testing.

2.1.4 Published EADS presentation entitled “Fire, Smoke Toxicity. Burn Through Resistance of Composite Fuselage”

This presentation is considered excellent and well worthy of close review. The presentation was not specifically dated, but is believed by me to have been published in 2003 and it cited as Ref. 12 herein and presented as figs 6 through fig. 34.

I would draw the reader’s attention to several points made in the EADS presentation.

1. The heat flux levels used in testing are much more in line with the 100-200 kW/m² range that can be anticipated for a fuselage fuel fed fire
case. This overcomes the 50 kW/m^2 limitation cited by Dr. Mouritz in his report. And the scenario is clearly explained in Fig 9. Next is fig 10, the authors illustrate the high heat flux all over the fuselage, thereby calling into question the limited “lower half of fuselage new thermal and insulation requirements of FAR 26.256(b).

2. EADS Researchers used a Cone Calorimeter approach as is presented in Fig. 11 of their presentation and fig. 12 gives a clear overview of correlation with Temperature/Heat flux.

3. Fig 13 gives a clear illustration of the high and unacceptable Peak Heat Release Rate (PHRR) when testing 2 mm thick structures at 100 kW/m^2 heat flux levels. I assume that this graph is for cf/epoxy, but that it is not specifically defined by EADS in this figure.

4. Requirements for low smoke density and low HRR are also cited by EADS researchers in Fig. 14.

5. Thermal degradation of Various Matrix Systems is recorded in Fig. 16 and please note that the four epoxies tested rank the worst with both Phenolics and PT-15 cyanate ester being shown as far superior.

6. Fig. 20 of the EADS presentation presents a comparison of PHRR of various matrix systems at 100kW/m^2. Clearly the four epoxies exhibit by far the worst whilst phenols and the PT-15 cyanate ester rank best.

7. Fig. 21 shows in graphical form a comparison of PHRR at 100kW/m^2 and clearly denies the superior performance of PT-15 and phenolics over epoxies used on Boeing 787.

8. Smoke emission comparisons are shown for various matrix systems in Fig. 22 of the EADS presentation and again. epoxies (similar to those used on 787) rank clearly the worst while, again, phenolics and PT-15 rank best. This data is repeated in summary form in fig. 23.

9. In reviewing Fig. 32 concerning toxicity aspects and summarizing the relative performance of all materials screened, the EADS researchers cite that for full scale fires (such as survivable crash landing the author adds) there is a large quantity of carbon dioxide over carbon monoxide, This is the reverse of the smoldering in-flight fire condition. EADS ranks both PEEK and phenolics as uncritical and epoxies and others as partly critical due to NOx/Sox and rank PT-15 as critical due to HCN*, while noting that such toxicity may not become a no go criteria for the fuselage skin as long as combustion products do not reach the aircraft interior. ** Author’s note: From my perspective I would also add unacceptably high PHRR for epoxies and lateral flame spread.
Fire Smoke Toxicity: Burn Through Resistance of Composite Fuselage

Agenda
- Introduction: Burn Through Resistance for CFRP Fuselage (in Luft2)
- Materials for Fuselage sking: PTFE, Phenolic, Borstar, BMM, PEEK, EP
- Influence of Fibers: Performance investigated for Glass and Carbon
- Investigation of Bonding/-Constructions at „Burn Through“
- Assessment of Core Materials
- Remarks concerning Toxicity
- Final Results at the End of Luft2 Investigation Program

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PST: Burn Through Resistance of Composite Fuselage

Fire scenario for Composite Fuselage with maximum thermal impact: Burn Through Conditions

The worst case scenario is given by a kerosene fire following a crash caused by an emergency touch down.

External Post Crash Full Scale Fuel Fire
Temperatures >> 1100 °C and Heat Flux max. 150 kW/m²
These conditions are extreme with respect to the Burn Through Resistance of composite materials.

5 minutes for complete evacuation of passengers
Up to 5 minutes: no burn through and only moderate temperature increase at interior

PST: Burn Through Resistance of Composite Fuselage

Fire test at laboratory-scale by CONE Calorimeter

State of the art fire tests are run at low heat loads representing fire at intensity, e.g. UL94, B1B, O90 with T up to 750°C.
These tests are of course not useful to simulate „Burn Through“

Simple tests using more powerful burners for T > 1000°C generate only qualitative/vague rating for burn through resistance
like: FAR 25.809/853; FAR 23.1191

A complete characterization is generated by CONE-Calorimeter (according to ASTM E1334)

PST: Burn Through Resistance of Composite Fuselage

Advantages of CONE Calorimeter:
- Variable Heat/Flux for fire scenarios from smouldering to full scale fuel fire
- Determination of Heat Release Rate
- Determination of Smoke Density
- Online-determination of CO/CO₂ + toxic gases (nitric)
- Determination of Mass Loss
CONE: Correlation of Temperature / Heat Flux

Example for Evaluation of CONE Results: Heat Release Rate

Screening of CFRP-Materials at Burn Through Conditions

Test of FST-properties by CONE Calorimeter at 100 kW/m² / 7.5 Min.
Requirements for CFRP-materials:
- Small Degradation/Mass-loss to get enough residual strength
- Low Heat Release Rate (HRR = Heat Release Rate, PHRR = Peak-HRR)
- Low Smoke Density
- Good Isolation, e.g. small temperature increase at the back side

Mass Loss at 100kW/m² / 50 kW/m² for G 926 Extrapolation to 150 kW/m²: time factor x 2

Thermal Degradation of various Matrix-systems

Thermal Degradation of various Matrix-systems

PT 15 EP

EP multiaxial
*Author’s note:* As a result of this figure citing possible no-go of PT-15 due to HCN, the author contacted Dr. Maarten de Zwart of Stesalit AG
in Switzerland. He denied this EADS conclusion and kindly sent me a toxicity material certification for his formulation of PT-15 which I am including as Fig. 35 and am citing as ref. 13 which shows that his formulation of PT-15 modified cyanate ester has HCN levels which are very low and only around 2% of permissible maximum HCN levels. I am sure that this HCN debate is now ongoing between EADS and Dr. de Zwart in Europe and I think we will soon determine whether EADS or Dr. de Zwart are correct regarding HCN hazard or lack of it for his formulation of PT-15

Here, I would also cite as a reference Dr. de Zwart’s excellent SAMPE paper published in 2002 where he reviews the excellent FST and mechanical properties of his cyanate ester formulation (Ref. 14).

10. Finally, in my review of the excellent EADS presentation, I would refer readers to Fig. 34 which summarizes the results of the Airbus sponsored DLR Lufo2 program re candidate matrices for Cf commercial fuselages. These are as follows:

Concerning matrix burn through resistant outer shell:
   a. PT-15 is best choice
   b. Peek and Blendur have some drawbacks
   c. Epoxies even with flame retardants are not suitable for burn through
   d. BMI’s are not suitable for burn through \n   e. Phenolics have insufficient strength for structural applications

EADS conclusions continue as:
   a. Only double shell sandwich construction generate sufficient thermal protection for the interior and that this concept shows some problems using state of the art epoxies for loaded structure at the inner shell (further optimization needed)
**TOXICITY**

**Material Certification**

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<td>Besuch vom 14.06.2005</td>
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**Test method**

NBS Smoke Chamber in accordance with ABD 0031 (latest issue)

<table>
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<th>Test mode</th>
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<tbody>
<tr>
<td>Gas component</td>
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<td>Sample 2</td>
<td>2</td>
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</tr>
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</tr>
<tr>
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<td>150</td>
</tr>
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</table>

Langenthal certifies that the above mentioned material has been tested in accordance with the terms of the order. (Unless otherwise stated it is to the specifications quoted hereon.)

Test results comply with the requirements of ABD 0031  
\[\checkmark\text{yes} \quad \square \text{no}\]

Langenthal 20.06.05 / mu

**FIG. 35 Stesalit AG Input re HCN levels of Modified PT-15**

This report is part of a series of nine reports for the ACT( Advanced Composite Technology) under the direction of NASA-LaRC and all work was performed by the Boeing Commercial Airplane Group, Seattle, Washington spanning a period from May 1989 through December 1995 and is devoted to the development of advanced Composite transport Fuselage Concepts and clearly this early work under NASA funding and aegis led in turn to initial development efforts via Sonic Cruiser and 7E7 to the current 787 program. Hence there is a direct historical link from this report and the 787-8 and series.

I do not propose to quote at length from these reports, but merely wish to cite the following from Section 5.5.10 (Page 5-20) re Crash and Fire Worthiness which directly pertains to the FST subject at hand as written by Boeing engineers:

“Requirements (i.e. FAR 25.561) and objectives related to emergency landings and ditchings for current aircraft types are designed to provide passengers with a reasonable chance of surviving the impact and evacuating the airplane……….Current requirements and objectives related to post-crash fire protection were developed around the ability to evacuate passengers from aircraft with aluminum fuselages. Criteria need to be established for composite fuselages to ensure equivalent safety levels. The key concern is whether the use of composites materials would adversely affect passenger evacuation. Composite materials are expected to offer better stiffness and strength retention in a fire than aluminum, thereby delaying loss of structural integrity. In addition, composites have been shown to be more effective in protecting the passenger compartment from external fire. Composites are also expected to act as a better thermal insulator, reducing the risk of auto-ignition and smoke emission from interior materials. However, the composite material itself may ignite (Author’s emphasis added), introducing fire into the airplane interior. Smoke evolved by the composite on the cabin side may enter the passenger cabin and inhibit passenger egress. Generation of combustible smoke could result in a flash fire within the fuselage cabin.

So here is Boeing focused upon burn through as a criteria from the start of composite fuselage research via NASA funding, but is clearly concerned regarding the composite fuselage externally igniting and thereby introducing FST into the passenger compartment back in the early to mid 90’s. Also, I believe that this potential hazard is present based upon auto ignition data that this paper presented earlier and I believe Boeing made an early error in limiting their concerns to “may ignite”, when clearly, with a very low auto ignition temperature in the 560-600 degree F range, obviously the exterior in a fuel fed fire survivable crash scenario (or from possibly from frictional heating in a wheel up landing case), in my opinion will ignite with high FST
and associated high lateral flame spread rates. Finally and notably, the Boeing study does not appear to address ruptured or penetrated fuselage scenarios as so often occurs during survivable crash landings as will be illustrated in detail later in this paper.

Boeing’s concerns re lack of any regulatory criteria for external fires in composite fuselages and structures are justified and I would cite a far later paper (Ref. 16 by Lyon, Moulton et al) published in November 2005 which again cites lack of any criteria from FAA concerning external composite fires. Specifically, ref. 16 states on page 1:

“Currently, no fire resistance requirements exist for external composite structures on airplanes”

And:

“About 50% of the structural weight of the new Boeing 787 is proposed to be composites, including for the first time a composite fuselage and wings on a large commercial airliner”.

I note that the cited paper addresses addition of phosphorus to aid in fire resistance of epoxies, but only tests for early OSU based interior fires in the 35-50kW/m2 range and not for fuel fed external fires. In addition, the EADS research work cited and discussed earlier in Section 2.1.4 in Fig. 34 of this paper specifically states:

“Epoxies even with flame retardants are not suitable for burn through.”

Since Boeing, NASA and FAA have been involved with developing such all composite structures since the late 1989 period, a time spanning at least 18 years, I find the lack of any FAA standard whatsoever concerning external composite structures to be alarming and inexplicable. Clearly such FAA regulations are vital and their omission brings into play yet another potential large FST hazard for the 787 and similar subsequent composite aircraft in the commercial arena.


This is clearly a key paper concerning the FAA and Boeing's overall approach to 787 fire safety and I will quote from the Introduction and Background section in full concerning the first paragraph, namely:

“In the majority of survivable accidents accompanied by fire, ignition of the interior of the aircraft is caused by burning jet fuel external to the aircraft as a result of fuel tank damage during impact. One important factor to occupant survivability is the integrity of the fuselage during the accident. Usually, there are two possibilities that exist in a survivable aircraft accident: (1) an intact fuselage and (2) a compromised
fuselage from either a crash rupture or an opened emergency exit, which allows direct
impingement of external fuel flames on the cabin materials. Based upon consideration of
past accidents, experimental studies, and fuselage design, it is apparent that fuselage
rupture or opening represents the worst-case condition and provides the most significant
opportunity for fire to enter the cabin. Past FAA regulatory actions governing interior
material flammability were based on full-scale tests employing a fuel fire adjacent to a
fuselage opening in an otherwise intact fuselage. This scenario, in which the cabin
materials were directly exposed to the intense thermal radiation emitted by the fuel fire,
represented a severe but survivable (my caps and bolding) fire condition and was
used to develop improved material flammability test standards. However, in some crash
accidents, the fuselage remained completely intact (no rupture or openings) and fire
penetration into the passenger cabin was the result of a burnthrough of the fuselage
shell”.

The authors then go off and blithely examine only intact fuselages, which, as I have already cited earlier in this paper represent only a small
minority of 23% of survivable fire crashes. Conversely the FAA authors ignore the vast
majority (73%) of ruptured or compromised fuselages already cited herein via the both
the Cranfield report and my own extended list of ruptured and compromised survivable
crashes as detailed later in this paper.

This is an astounding position concerning the FAA, as the FAA
authors in the paragraph cited above fully acknowledge that the interior materials
regulations represent “a worst case but survivable condition”. I found this whole
approach to 787 FST and crash-worthiness completely and utterly fallacious on the part
of the FAA. If we are only going to test intact fuselages, a clear and minor minority, then
why bother to have interior flammability standards as established by the FAA
themselves? The FAA is on a logical cleft stick and their rationale, test procedures,
standards and testing of the 787 fuselage make no sense whatsoever.

We engineers test to worst case, but survivable standards, as any
other less severe and minority oriented subset of survivable intact fuselage crashes make
a mockery of FAA 787 certification standards. The reasoned engineering, not PR
response, I note, of both Boeing and the FAA is eagerly awaited by the author. Or is the
new and far worse position of the FAA and Boeing now that the moment we have a
fuselage rupture or compromised fuselage in a fuel fed fire, the vast majority of cases, I
note, is our new FAA certification standard “Forget all occupants in such previously
survivable crashes”?

Clearly this is a disgrace and should not be allowed by DOT Inspector
General, NTSB, EASA and all other governing and certification agencies. I would also
hope, without hope, to quote Eliot again, that both Boeing and top FAA management
would see and correct the folly of their path before it is too late.

Section 2.1.7 Review of “Blanket Protection” authored by Wayne Rosencrans,
Aerosafety Magazine, April 2008, Flight Safety Foundation
I will not spend much time concerning this 2008 article, which is frankly and primarily a puff-piece concerning Dr. Timothy Marker of the FAA and his lower fuselage insulation scheme promulgated and edicted by the FAA.

I do wish, however, to dispute with a pair of statements attributed to Dr. Marker. I take particular umbrage at the attempted re-writing of actual aircraft accident history concerning both the 1985 Boeing 737 Manchester tragedy and the Air France A340 August 2005 overrun crash at Malton, Canada. The subject article attributes Dr. Marker saying (I don't know whether his statement or journalistic imagination) that both of these crashes were burnthrough crashes, thereby bolstering the present FAA and Dr. Marker's crusade and edict for lower fuselage insulation as the path for 787 certification.

I dispute both of these assertions and will first quote from the UK Accident Report concerning the Manchester 737 Crash, (Ref: Transportation Safety Board, Aircraft Incident report , No: 8/88), and specifically from the Factual Information section, namely:

“During the latter stages of the abandoned take-off, and just as the aircraft turned towards taxiway link Delta, the right rear door was seen by external witnesses to be open, with the slide deployed and inflated. A stewardess was initially visible in the doorway, but the door and the slide were obscured by this smoke as the aircraft stopped. No one escaped from this door” and again from the same report, “As the aircraft came to a halt and at the instigation of other passengers, a young woman sitting in row 10 seat F (10F), beside the right overwing exit, attempted to open it by pulling on her right hand arm-rest which was mounted on the exit hatch. Her companion seat 10E, the center seat of a row of three, stood up and reached across to pull the handle located at the top of the hatch marked “Emergency Pull”. The hatch, weighing 45 lb, fell into the aircraft, pivoting about its lower edge to lay across the passenger in 10F, trapping her in her seat. With the assistance of a man in row11 behind the woman, the hatch was removed and placed in vacant seat 11D. The passenger in 10F and 10E then left the aircraft cabin through the overwing exit onto the wing followed by other survivors. This exit was open about 45 seconds after the aircraft stopped”.

So clearly, in my mind, irrefutably, this was a compromised fuselage by the FAA's own definition in Section 2.1.6 above. And a compromised fuselage does not a burnthrough of intact fuselage make to use the Bard as we should.

Next let us look at the Canadian Transportation Safety Board Accident report (ref: A05H0002, “Runway Overrun and Fire Airbus A340-313 F-GLZQ, Toronto/Lester B. Pearson International Airport, Ontario 02 August 2005) and quoting from that report which clearly states in Section 1.12.6 L2 Emergency Exit:

“The L2 door, which was reported to have opened while the aircraft was decelerating” and, again, “Photos submitted by an evacuating passenger clearly shows that the L2 door was open and the emergency slide was not deployed........... The interior of the door was heavily damaged by the fire, the lining and insulation approximately 90% consumed” And a further quote from the report: Section 1.12.2; “Major Break-up of the aircraft occurred only after it descended into the ravine.” Next, from Section 1.15.2 “the fire started on the aircraft exterior before the aircraft came to a stop; and smoke entered the cabin through the opened evacuation doors before the evacuation was complete”.

Again, clearly, the L2 door was open during deceleration and many other evacuation doors were open and smoke entered the cabin through the opened evacuation doors before the evacuation was complete.

So, to repeat, this is again a compromised fuselage under the FAA’s own stated criteria as quoted earlier rather than an intact one. In light of this clear evidence concerning both crashes, I would hope and trust that both or either Dr. Marker and Mr. Rosencrans recognize and acknowledge their errors in an expeditious manner. We do not need to try and rewrite history to attempt to justify the FAA and Boeing adopted certification path and rationale for the 787, our industry deserves better in my opinion.


This paper is clearly very important and pivotal to my overall thesis in attacking the current biased, doubtful and highly questionable Boeing and FAA adopted basis in promulgating only burnthrough of INTACT fuselages as the overall rule making criteria. Prior to my finding this paper since my initial SAMPE draft paper and its appendix, I had to rely on a multitude of FST excellent papers and other facts and by addressing only ruptured or compromised fuselages, I had a strong array of facts and my own assembled database, via the good offices of Dr. Harro Ranter and many others who have compiled a series of excellent web sites compiling and listing survivable crashes. However, I could still be considered out on an engineering limb by some, however, with some further detailed research into AGARD papers from 1996, finally, I had an independent, verifiable and impeccable third party source to substantiate, verify and corroborate my own research.

This paper represents a key source, just as the cited and review of the latest FAA paper presented in Section 2.1.7 above establishes the logical fallacy underlying the FAA and Boeing certification and rule making position concerning the 787. I wish to summarize the key tree table from the Cranfield paper into this section and I am most grateful for their diligent data gathering and excellent paper.

Here is a text summary of the relevant crash survey figure:

Fire Survivable Accidents
1958-1994 (217 cases)

Significant Impact Occurred = 187 cases
Within these 187 cases, the breakdown is follows: (my addition for reader clarity):

- No Significant Fuselage Disruption = 43 cases
- Significant Fuselage Disruption = 136 cases

We can now derive the relevant percentages as follows:

\[
\text{Significant Fuselage Disruption} = \frac{136}{187} \times 100 = 73\%
\]
\[
\text{No Significant Fuselage Disruption} = \frac{43}{187} \times 100 = 23\%
\]

There is a small but negligible addition error here, either via the original Cranfield authors or myself, but clearly and irrefutably the vast majority of survivable cases result in significant fuselage disruption, which I deem to represent ruptured, compromised or opened fuselages. Hence the FAA and Boeing in their single minded pursuit of only intact fuselages are only addressing a small minority of survivable crashes rather than the real world of survivable fire crashes.

My own list in Table 1 below only cites ruptured fuselages, but differs from the Cranfield database as I list all, as I deem them, survivable crashes and I employ the criteria of a minimum of 30% survivors and all fuselages are ruptured, penetrated, compromised and opened thereby allowing the ingress of FST products into the cabin. I list both fire survivable crashes involving both fires and no fires. I can find no set criteria for “Survivable” for such crashes and accidents, therefore I am leaving myself open to critiques from others holding differing survivable criteria, however I believe that my survivability criteria is defensible as a middle ground position between disparate “survivable” criteria employed by various agencies and experts that I discuss in detail later in this paper.

Next, I wish to quote from the text of this key Cranfield paper. In the Introduction, the authors state:

“Most incidents involve fire, which can expose potential survivors to a lethal thermo-toxic environment and contribute significantly to overall fatalities”

In addition, quoting again from the Macey et al Cranfield paper:

“As well as their potential diversity, aircraft fires also tend to involve many complex, highly interactive and dynamic phenomena. These attributes can make it difficult to integrate knowledge obtained from past events or plan purposeful research programs to investigate issues of concern in aircraft fire safety. Similarly, it is also far from straightforward to perform a satisfactory analysis of the effectiveness of current or proposed new safety measures”.

Next the authors state:

“Faced with these challenges, those committed to minimizing the hazards of fire in aircraft possess only limited resources with which to work from.”
Further, there is another statement that, hopefully, some key engineers at both Boeing and the FAA might well pay close attention to and it is as follows:

“However, if the results of such work are to be of real value, care must be taken to ensure that test conditions adequately represent those likely to be encountered in actual aircraft accidents”.

Given the long list of survivable accidents later presented herein, all of which involve survivable crashes with ruptured and compromised fuselages, can the FAA or Boeing actually claim and justify to their peers that they are meeting this requirements where they continue to retreat from the real and proven world of survivable accidents and cling to an unrealistic minority position focused on a mere 23% of crashes while ignoring the vast majority of 73% of compromised, ruptured and severely disrupted fuselages as cited by the excellent and objective Cranfield authors in the subject paper?


I debated for a brief period whether to place this excellent paper in the Appendix, which focuses on the hazard implications demonstrated by the B-2A crash in Guam in 2008 or whether to place it in this revised section alongside all the other newer papers, Eventually, practicality and sympathy for the reader won out and I am reviewing and citing it here.

However, given the enormous public and occupant safety implications concerning composite aircraft crashes, I strongly urge all readers to review that appendix in detail alongside and in conjunction with this report. I do not believe that any responsible safety or composites aeronautical engineer can ignore the implications of the B-2A Guam crash as fully detailed in the appendix in spite of the current rather silly attempts of Boeing PR to create a differentiation between military and commercial epoxies, where hardly none exists.

In the B-2A crash report, the investigators reported being surprised by the duration and intensity of flare-ups, smoldering and recurring spot fires for two to three days, not hours, after the fuel portion of the fire was extinguished in the first thirty to forty minutes. The continuing fires and flare-ups were epoxy fires not fuel fires and the St and safety implications are highly significant. However, clearly one part of the USAF was not adequately communicating with other parts of the Air Force as this report, written four years prior to the Guam crash details.

The Abstract of the paper states: “An evaluation of Composite Wing Boxes has been conducted to demonstrate the severity of composite fires and evaluate damage assessment techniques for large scale composites. The fire test objective
was to simulate the fire that would occur following a fuel spill from a large composite aircraft.

Although the report concerns itself with B-2A wing boxes, clearly its results can be anticipated for fires concerning large composite aircraft as the authors state. Next I will quote from the introduction, part 1 of the report:

“Composite materials also pose fire safety concerns due to the combustible nature of the organic matrix. The inherent chemical nature and complexity of polymer matrix composites do not lend themselves to easy analysis of their behavior when exposed to fires. Heat transfer is anisotropic in composite materials and they selectively burn, produce smoke, release heat, chemically degrade, char and delaminate”

Further in the same paragraph “Due to the inherent complexity of composite materials, flammability is not readily quantified for complex, commercial systems and is a continuous on-going process”.

In the next paragraph, the May, 2004 report states:

“This Paper describes initial studies in understanding (my bolding) fire-induced damage and degradation mechanisms of composite materials typically used in military aircraft. Two composite wing boxes, fabricated from AS4/3501-6 graphite/epoxy, were tested under realistic pool fire scenarios, for two different response times ((1 minute and 5 minutes) for extinguishing fires”

Please note, all readers, that this approach and test scenario by the USAF is full scale fire testing as I am advocating throughout this report and is a far more realistic survivable crash scenario than anything accomplished or attempted to date on the 787 program by either Boeing or the FAA and we are now in the middle of 2010, six years later. And the authors state it is only “initial studies in understanding fire-induced damage and degradation”. And Boeing and the FAA was planning to certify the 787 in 2007, My not very easily engineering mind boggles at the hubris of Boeing and FAA and the disregard of the full FST safety hazards involved. And while both are busy refusing to perform realistic full-scale ruptured and compromised fuel fed fire tests, the USAF is clearly far more realistic and aware of these critical issues.

And further in Section 2, Composite Wingbox Burn Test, the report states:

“With current standards, Crash/Fire vehicles may not arrive in time to prevent ignition of these materials. Composites continue to burn after the liquid fuel fire is extinguished. The continuing fire produces as much heat as pinewood when burning. Final extinguishment will probably require breaking apart obscuring structures and fully saturating smoldering areas with wet extinguishing agents. Fire department response to a fire on or near an aircraft must be within seconds to prevent irreversible damage”.

Now imagine the horrendous situation facing all of the aircraft's occupants and it is a sad and sobering reality.

Next we move on to quote from the wing-box fire test results and I invite the reader to compare them to the blithe comments from the latest FAA 2008 report and the “Blanket Protection” article cited and quoted earlier herein. I quote from the footnote accompanying Table 2 in the subject report:
“Typical thermal profiles are shown in Figure 5 for both burn tests, as measured on the exposed side (bottom) of the wing boxes. As expected, the 5 minute burn results in composite ignition and continued heat release and burn despite extinguishing the flame, indicating deep-seated fires within the structure”.

Clearly, I would hope by now, in light of all of the fire hazard and FST dangers presented herein, without dispute amongst my fellow aeronautical engineers, there is a huge fire and FST issue with epoxy composites of whatever ilk and one that cannot be lightly brushed aside or danced around by either any responsible certifying authorities or Boeing. These types of deep seated self-ignited fires are not, repeat not, currently faced with commercial aluminum aircraft now in service and represent a severe hazard to both all the unfortunate 787 occupants and to responding fire-fighters. It is for this reason that I strongly urge all readers to review the accompanying Appendix focusing on the B-2A Guam crash.

If the FAA and Boeing both refuse to conduct full scale FST fire tests on real large ruptured composite fuselages and wings, we can at least be most thankful to the Air Force researchers and authorities at Tyndall AFB for recognizing the major hazards and having the foresight and gumption to realistically test for such hazards on representative full-scale articles. This, along with the 2008 accidental full scale crash and fire of the B-2A in Guam, both stand as stark and self-evident proof of the high hazards and dangers involved in large scale aircraft composite survivable crashes and the onus is now clearly placed, four square upon both thee FAA and Boeing to prove the degree of hazard via an objectively selected full-scale fuel fed fire test on a ruptured or significantly compromised 787 fuselage. This engineer sees no room for further debate if Boeing and the FAA are truly committed to no diminishment of occupant safety in survivable crashes.

Section 2.1.10 Summary of Section 1 and 2 FST risk assessment, papers and reports

After reviewing all of the reports, papers and presentations referenced in these two subject sections, the author concludes that a major potential hazard exists concerning FST in the new generation of commercial aircraft, particularly with respect to the Boeing 787 series. This undoubtedly comes as no surprise to experts in the field, but I would be delinquent to the composites community if I did not cite some specific items to support this conclusion. These are, based upon my knowledge:

1. We have replaced a well understood aluminum fuselage structure and a non-epoxy, highly rated largely phenolics based interior and have now surrounded the passenger and crew compartment completely with a combustible and flammable cf/ epoxy matrix which is banned for interiors by the FAA itself. This hazard is well proven over many decades and has been extensively tested by FAA and other agencies. If Boeing and FAA or other certifying agencies have not performed a series of full scale fuel fed FST tests upon ruptured fuselages or with down wind open exits, then clearly we are venturing into an unknown and hence, highly hazardous area. Without published Boeing test data
to support their selection of epoxies for primary structure we are clearly left with many unanswered questions.

2. I believe that Boeing has, in choosing an FST critical epoxy matrix for the primary fuselage potentially raised other hazards including; wheels-up landings, flip-overs and cartwheels, runway undershoots and overruns, all such previously survivable crashes are now called in question in light of that stated auto-ignition issues and having now lost around 1300 degrees F of previous ignition margin. Clearly, 2024 aluminum alloys melt at temperatures in the 900+ range, but it is ignition and fire, toxicity and smoke ingress that primarily causes passenger interior cabin FST hazards.

3. Boeing and the FAA appears to be focused only on burnthrough aspects, and has not, at least to my knowledge from published literature, addressed FST hazards resulting from ruptured or compromised fuselages with open exits combined with fuel fed fires as exist in a wide variety of survivable crashes. These are potentially critical issues in my opinion. I strongly believe that if Boeing has proof via full scale testing that I am wrong in this assessment that it is clearly in Boeing’s and our composites industry’s best interests to publish such data for peer review, critique re design of experiments and objective assessment. Boeing and our industry need the 787 program to be an outstanding success, just as is the case for EADS and Airbus concerning the A350. We can pray and hope for no survivable crashes or any other crashes, but, as engineers, we must be prepared for the worst and explicitly test for via all worst case, but survivable full-scale FST tests to determine if the selected epoxy materials to not diminish occupants chances of survival and egress.

4. The FAA has yet to impose, to my knowledge, any standards or regulations for external fires for structural composites, I n addition, nor has the FAA performed any full scale fuel fed ruptured or open exits for 787 style primary structural composites. This stands in strong contrast to the earlier extensive testing regarding similar fuselage structures in aluminum regarding interior materials which has stood the industry well. This places a major responsibility on Boeing and Airbus, in the absence of such regulations to set their own internal safety standards high and strive via full scale FST tests to demonstrate such levels of safety.

5. Boeing unfortunately appears to have selected amongst the lowest ranked materials for the primary structure fuselage matrix material thereby leading to, low ignition temperatures, high PHRR, smoke and toxicity hazards for all occupants seeking safe egress.

6. In contrast to Boeing, it appears that EADS believes, based upon its preliminary research that potentially a cyanate ester, specifically PT-15 is by far superior to epoxies re FST, thereby a dichotomy in design approaches exists between the two O.E.M.s or from my vantage point

7. The FAA has addressed the issue of FST in FAR 25.256(b) via a similar approach to Boeing, but this clearly neglects and ignores the vast majority of survivable compromised and ruptured fuselage fuel fed crashes as the cited 1996 Cranfield paper explicitly states, while potential auto-ignition of the
fuselage from wheels-up, undershoot and overrun aspects arise given the extremely low auto-ignition levels for epoxies.

8. Open exits, slides and doors and down wind survivable crash FST hazards also seem to have been minimized by FAA in the latest FAR 25.256(b) other than improving insulation standards for the lower half of aircraft fuselages. This approach appears to neglect ruptured fuselages, auto-ignition hazards, cartwheels, open doors and exits in a wide variety of survivable crashes as will be cited later in this paper. And as independently cited in the foregoing Cranfield paper at best this addresses a mere 23% of survivable crashes whilst ignoring the vast majority of such survivable crashes.

9. The author believes that the FST hazard case for cf/epoxy fuselages is clearly established and thus the onus must be on both O.E.M's and all certifying agencies to prove that no safety diminishment or regression has arisen from selecting all epoxy fuselages and, in my mind, this can only be proved via full scale independently selected and monitored compromised or ruptured fuselage fuel fed fire tests. The FAA in their latest Marker and Speitel 2008 papers, as cited above, themselves admit that such crashes are survivable and, hence, must be fully tested for via full-scale ruptured or compromised fuel fed FST tests and such tests must be performed prior to any certification being even contemplated by the FAA, EASA and all other responsible certifying agencies.

10. I have seen nothing to date suggesting that certifying agencies or O.E.M.s are working to improve passenger egress methods to protect them against clear and evident external FST hazards from epoxy composite fuselage fires, this is considered by the writer a feasible and short term approach to protect passengers’ egress in survivable crashes.

11. Conversely, and as a final summary note, to be totally fair to Boeing and its thousands of skilled and dedicated engineers, who I greatly admire, I wish to set out the other side of the coin If Boeing, on the 787, has indeed already performed a series of successful full scale ruptured fuselage or fuselages with open down wind exits fuel fed FST tests plus successful tests proving that wheels up auto-ignition is not a problem and can fully substantiate such successes via published engineering data and examined by rigorous and independent peer review, then nobody would more delighted and relieved than I. Further, I believe that the aerospace composites community would be equally pleased. However, in the absence of any such proof to date from Boeing, the concerns and questions as stated above must stand as potential major hazards to passenger safety and egress.

Section 3: A Review of the Role of the FAA Regarding Safety and Certification and Published FAA Final Special Conditions re Potential FST fuselage hazards for the Boeing 787-8 Airplane

3.1 The Vital Role of FAA regarding Aircraft Safety
Clearly the FAA and NTSB both play vital roles concerning passenger safety for Part 121 commercial aircraft. Their roles are different and separate, however, as the FAA imposes and edicts conditions for certification and demands that manufacturers applying for Part 121 certification meet a wide ranging series of requirements largely based on prior experience, fatalities and overall experience. I wish to praise the FAA for fulfilling its duty over many decades just as I do together with the similar vital roles of other certificating agencies such as; the JAA, CAA and EASA agencies. It is clear public policy to separate certification and monitoring as practiced by the FAA and that of the post-accident investigation role demanded of the NTSB. This is a wise and necessary policy for our associated and all transportation industries.

I do not propose to deal in depth with this large public policy and safety issue, but would like to illustrate the FAA’s own view of their vital role. For ease of illustration, I am presenting the FAA’s own words concerning their wide-ranging responsibilities in aerospace from their web site directly (Ref. 17) and this is presented as Fig. 36 below. There is no doubt that the a priori demands are notably different from the post-crash investigative ex post facto role demanded of the NTSB and here I wish to cite for review the NTSB’s view of the vital role of the FAA and I have chosen the NTSB report cited in Ref. 17 for purposes of this discussion. The referenced NTSB report is long and detailed and praises the long history of enhancing passenger and aircraft safety. While praising the FAA and its certification standards as “sound”, the NTSB cites a series of four fatal crashes, namely; American Airlines 587, Alaska Airlines 261, US Air 427 and TWA 800 for specific review and draws attention to what the NTSB sees as certain deficiencies in each certification process concerning each of these crashes. In dealing with certification aspects concerning safety the subject report clear and states on Page 4 as follows:

**Type Certification** is a regulatory process that the FAA uses to ensure that the design of a transport-category airplane meets all applicable safety standards. Safety standards are embodied in Federal Aviation Regulations (FARs) with associated guidance provided in directives and advisory circulars. Unlike engineering design that must balance potentially conflicting safety, cost, schedule, performance, aesthetic and manufacturing elements of a design, certification focuses on a single aspect of the design—safety—to ensure that it meets the minimum standards established by law.”

And later the report states on Page 29, the NTSB report states in discussing the American Airlines Flight 587 crash that:

“Although it acknowledges that no certification standards for rudder pedal sensitivity exist, the Safety Board stated the following……”

Later, no the same page, the report states:
“The Safety Board investigation also revealed that certification standards were deficient with respect to pilot interaction with the A300-600 rudder system. Specific standards set forth in regulations to address pedal force requirements, proportional rudder movements, and handling qualities did not appear to the Board to sufficiently address the risks of associated with pilot use of the rudder, especially at high airspeeds.”

So, even when *no regulations exist concerning certification*, (my emphasis added), still the Safety Board faults certification deficiencies. Surely, there exists a clear parallel here with no existing FAA regulations regarding external structural composite fires regarding FST risks present in cf/epoxy fuselages on such aircraft as the Boeing 787-8 and the NTSB is clear that the role and responsibility of the FAA in certificating these new generation of commercial aircraft must focus only on a single aspect, namely safety; and it must ignore all other concerns such as cost, schedules, performance, aesthetic and manufacturing elements. Nothing could be clearer in my mind and I would hope that the FAA internally reviews their previous position in light of the NTSB report reviewed above.

3.2 Review of final FAA findings concerning FST
Sensitive Special Conditions for the Boeing 787-8 Airplane

All proposed and final Special Conditions are fully presented on the FASA web site, [http://rgl.faa.gov](http://rgl.faa.gov) and I will refer the reader to that web site for all specific details. A total of nine Special Conditions were issued in the first half of 2007 and only three of these I considered directly to pertain to FST hazards as this paper focuses upon. The three Special Conditions are; Special Conditions Notice Number; 25-07-05-SC, Notice Number 25-07-03-SC and Notice Number 25-360-SC (These Special Conditions and pertinent dates and titles are listed as Ref. 18, 19 and 20).

As noted, I submitted my formal comments to the FAA for each of these Special Conditions and, generally I am cited by the FAA as the first commentator with my clear emphasis re FST hazards making my identity clear to all readers.

Clearly two of the three Special conditions arose from previous crashes and over-runs; specifically Ref. 20 appears to stem from the fatal Swissair flight 111 MD-11 crash over Nova Scotia while the Ref. 18 S.C appears based upon the AF 358 A340 over-run crash and fire in Toronto on August 3rd 2005.

3.2.1 Final Special Condition re fuel tank and wing requirements review (Ref. 18)
Ref. 18 is, to my mind, the most detailed of all the three referenced Special Conditions related to FST in my view and from Pg. 3 of the final S.C, I quote as follows:

“Adevisory Circular (AC) 20-107A, Composite Aircraft Structure, under the topic of flammability, states: “The existing requirements for flammability and fire protection of aircraft structures attempt to minimize the hazard to the occupants in the event ignition of flammable fluids or vapors occurs. The use of composites structure should not decrease this existing level of safety.”

Clearly the author is the subject S.C. is dealing with wing and fuel tank fire hazards, but equally clearly in my mind, such hazards equally are present for cf/epoxy fuselages. The FAA author of the subject S.C also states:

“The relevance of the wing structure is that post crash fire passenger survivability is dependent on the time available for passenger evacuation before fuel tank breach or structural failure.”

This survival time is set as five minutes for current commercial Type 121 aircraft by the FAA. I concur with the S.C. writer, but rupture of the fuel tank can cause almost immediate severe fuel fed fires, as witness the recent Naha, Okinawa 737 on ground fire and miraculous total evacuation of all passengers and crew on 08-20-2007 where clearly the 165 passengers had only seconds rather than five minutes chance to egress. (Ref. 21) due to a fuel tank rupture and subsequent massive fire which rapidly destroyed the aircraft.

The FAA author also cites the following:

“The FAA has historically developed rules with the assumption that the material of construction for wing and fuselage would be aluminum. As a representative case, Sec. 25.963 was developed because of a large fuel fed fire following the failure of fuel tank access doors caused by uncontained engine failures. During the subsequent Aviation Rule-making Advisory Committee (ARAC) harmonization process with the JAA, the structures group tried to harmonize the requirements of Sec. 25.963 for impact and fire resistance of fuel tank access panels. Both authorities recognized that existing aluminum wing structure provided an acceptable level of safety. Further rule-making has not yet been pursued.”

Later the author states in his discussion of his particular Special Conditions that:

In order to provide the same level of safety as exists with conventional airplane construction, Boeing must demonstrate that the 787 has sufficient post crash survivability to enable occupants to safely evacuate in the event that
the wings are exposed to a large fuel fed fire. Factors in fuel tank survivability are the structural integrity of the wing and tank, flammability of the tank, burn through resistance of the wing skin, and the presence of auto-ignition threats due to exposure to the fire.”

Clearly the author is demanding and requiring specific fuel fed fire tests of Boeing and rightly so and his statements stand in sharp contrast to other S.C. authors concerning Fuselage and FST risks as are discussed below.

I would further quote from the detailed and excellent FAA’s author’s views as stated on page 4 of thee final SC, namely:

“The extensive use of composite materials in the design of the 787 wing and fuel tank (Author’s note: I would add and fuselage as clearly the degree of change is equal and equivalent to that of the wing and fuel tank) is considered a major change from conventional and traditional methods of construction. This will be the first large transport airplane to be certificated with this level of composite material for these purposes. The applicable airworthiness regulations do not contain specific standards or post-crash fire safety performance of the wing and fuel tank skin or structure. (Author’s note: this equally applies to the fuselage, of course).”

So here we have the FAA stating in unequivocal terms that this is the “first large commercial aircraft” to be certificated and most importantly and critically that “applicable airworthiness regulations do not contain specific standards or post-crash fire safety standards” as I have stated throughout this paper and the FAA author rightly and correctly goes on to demand of the O.E.M. manufacturer that:

“Boeing must address a range of fuel loads fuel loads from minimum to maximum, as well as any other critical fuel load” and that:
“Therefore to be consistent with existing capability and related requirements, the 787 fuel tanks must be capable of resting a post-crash fire for at least five minutes.”

Here the FAA Special Condition author is properly and clearly that requiring that Boeing perform suitable wing and fuel tank tests to verify and demonstrate compliance as I would fully expect from the FAA. Finally, the FAA addresses this author (for clarification, my formal comments are listed Comments, 5, 6, and 7) in his final comments. Here the author states that:

‘Cabin safety special conditions have been developed and published for comment in Special Conditions No. 25-07-09-SC, Docket No. NM#&## published April 26, 2007 (72 FR 20774). These Special Conditions require that the 787 provide the same level of in-flight survivability as conventional aluminum fuselage airplane. This includes its thermal/acoustic insulation
meeting requirements of Sec. 25.856(a). These Special Conditions state that resistance to flame propagation must be shown, and that all products of combustion that may result must be evaluated and found acceptable”

And later on page 8 states that:

“We would like to note that the scope of these special conditions (i.e. Ref. 18) is limited to the fire safety provisions of the fuel tanks and wing during a fuel-fed ground fire. These special conditions are not intended to address the structural crash-worthiness of the airframe”.

So, we are rejected as good old “out of scope” and handed back to the fuselage group of the FAA. Hence we must next review the final FAA statements of the other two Special Conditions, namely Ref. 19 and 20 as previously cited.

3.2.2 Final Special Condition re Crashworthiness (Ref. 19)

Again my comments are rejected as “Out of Scope”, which I find interesting, to say the least. Here, in this response, the FAA author is far weaker than was the case in Ref 18 from my viewpoint. My request for a forward velocity vector which I desired to assess and test for auto-ignition hazards during a wheels up landing incident, which should be nearly always fully survivable in my view, was rejected via a brief statement, namely:

“We agree that the fuselage post-crash survivability including FST hazards that may be associated with the use of carbon fiber epoxy structure is an important issue. This issue is outside the scope of these special conditions however”.

Rather unkindly here, I must view the foregoing FAA statement as a load of cod’s wallop in my view, as it clearly is a key and vital aspect of crash-worthiness and will be illustrated in the following section of this paper (Section 4). Clearly there are a wide range of survivable crashes which the FAA knows well as do all certifying authorities worldwide and the NTSB. Many of these survivable crashes involve ruptured fuselages and penetrated fuselages allowing ingress of FST into the passenger compartment plus, in many instances ground fuel-fed fires as well. Hence, in the author’s view such previously survivable crashes can never be deemed out of scope by FAA. Here we are getting to the nub of what I strongly believe are the errors and omissions by the FAA concerning FST hazards and survivable crashes. This will be expanded upon later, but I wish to note the written emergence of these errors and fallacies concerning survivable crashes as will dealt with in detail in the next section.
The FAA author of Ref 19 continues:

“It is being addressed in conjunction with the requirements for Section 25.856(b) relating to fuselage fire penetration protection”

There appears to be a minor internal disagreement between Ref 18 and ref. 19 re (a) vs (b) re Section 25.856, but this, I believe is minor point.

In my view, I can only be bemused at this total emphasis only on burn through and reliance upon upgraded standards to the lower half of the fuselage only re Sec. 25.856(b) by both the FAA and apparently Boeing while neglecting and totally ignoring a wide range of clearly survivable crashes as established by past crashes, as far as I can determine, a wide range of ruptured and penetrated fuselages, cartwheel landings and open exit and slide crashes thereby presumably allowing ingress of fuselage and wing FST products into the passenger compartment with potentially disastrous adverse effects upon passenger safety and ability to survive and safely egress, as cited elsewhere is this paper. This author, again, believes that only via full scale fuel-fed can Boeing and the FAA properly assure itself of the degree of risk represented by ground fire penetrated and ruptured fuselage FST and then move to address and solve the critical safety issues involved if my thesis is proved correct as cited herein.

To put the problem very clearly yet again, we are moving from aluminum fuselages and aluminum wings with 12-15% composites usage for empennages and secondary structures to a new generation of composite fuselage and composite wings in flammable and combustible epoxies with know FST hazards. How can we prove their safety without full scale fuselage FST tests?

I hope that Boeing internally has recognized the problem and performed the necessary series of tests, but aerospace safety and certification should not be founded upon hopes, rather it should be founded on a series of well designed tests to accurately assess and prove or disprove the FST hazard to passenger and crew safety.

Returning to Ref. 19 again, clearly the FAA author does NOT understand the vast differences of around 1200 degrees F between auto-ignition temperatures between the new generation epoxy fuselages and past aluminum structures as I have cited earlier in this paper, for he states:

“The factors (principally deformation, mass and friction) that govern impact response characteristics in the longitudinal direction are not significantly altered with the change from metallic to composite fuselage structures. Given the similarity of the 787 to the current fleet, the FAA has determined that these special conditions will be limited to an assessment of the 787 in the vertical impact direction”.
Given my previous detailing of the auto–ignition wheels up landing problem in Section 1-2, I must refute the FAA claim and conclusion cited above. Finally, concerning the cited Crashworthiness Special Condition included as Ref. 19, I must cite the following statement from the final section of the FAA author’s “Discussion of Comments”, namely:

“The FAA’s role is to verify that the special conditions have been complied with, rather than to develop a method of compliance. While there are merits in conducting a full-scale test, there are other approaches using tests and analysis that can actually yield more data than would a single test. Thus, we consider it more effective to establish the standards and encourage (my emphasis added again) the applicant to develop the most effective method of compliance”.

Again in reviewing Ref. 19, such statements, very frankly, appear to be in non-conformance with established FAA tradition, regulations and standards in light of normally demanded tests such as the static and fatigue tests required and FAA exhaustive testing and enforced regulations concerning FST hazards for aircraft interiors for all certifying all Part 121 commercial transport airplanes over the decades and I believe is a serious error on the certificating agency’s part. I believe that it can only be an abdication of the certifying responsibility for the FAA to stand aside and merely “encourage” the O.E.M. manufacturer and this engineer hopes that Boeing has viewed its responsibilities to the public in a far more serious light in the course of its internal development test program for the 787.

3.2.3 Review of In-Flight Fire Special Condition (Ref. 20)

This Special Condition focuses upon in-flight fires in inaccessible areas as occurred in the Swissair Flight 111 crash over Nova Scotia and was published by the FAA Northwest Office Fuselage Group also, but with a different author. I would cite the following from the final Special Condition, namely:

Conventional aluminum fuselage material does not contribute to in-flight fire propagation. As a result, there are no standards that address in-flight fire safety of the fuselage structure itself. The 787 will make use of composite materials in the fabrication of the majority of the wing, fuselage skin, stringers, spars and most other structural elements of all major sub-assemblies of the aircraft. As a result of this extensive use of a new construction material, the fuselage cannot be assumed to have the fire resistance previously afforded by aluminum in the in-flight scenario mentioned above. These special conditions require that the 787 provides the same level of in-flight survivability as a conventional aluminum fuselage airplane. This includes its thermal/acoustic insulation meeting the requirements of Sec.
25.856(a). Resistance to flame propagation must be shown and all products of combustion must be evaluated for toxicity and found acceptable”.

Turning to the public comments, where I am again comment 1. let me cite the FAA fuselage group’s response, namely:

“We agree with the commentator that consideration of post-crash fire safety must include all the factors that influence survivability, and not just focus on one characteristic. These special conditions focus on in-flight safety, so any issues related to post-crash safety go beyond the scope of these special conditions. Nonetheless, the FAA is equally concerned with post-crash survivability and is addressing this issue through separate criteria. In this case, because there are requirements related to post-crash safety in Sec. 25.856 (b), the approach will be via an equivalent level of safety finding in accordance with Sec. 21.21(b)(1). A summary of this finding will be available in the FAA Regulatory and Guidance Library at [http://rgl.faa.gov].”

The author notes that to date (01/04/2008), no such finding has been published at the subject FAA site, again all leaving us totally in the dark concerning any final certification discussions between the FAA and Boeing regarding the basis for a finding of equivalent level of safety or its basis.

It seems timely at this point, to cite what should and in the author’s opinion must be contained, at a minimum, in reach any valid finding of “equivalent level of safety” for the 787 airplane fuselage and passenger compartment by the FAA. These are:

A. Details and results of all Boeing full scale FST fuel fed fire 787 fuselage tests fully representative of past survivable crashes upon a variety of ruptured 787 fuselage barrel sections including heat flux levels, fire spread, toxicity, smoke data, fire ingress and all detailed FST test data and results.

B. Details and results of all Boeing full scale FST fuel fed 787 fuselage tests fully representative of past survivable crashes involving a series of down wind tests concerning open exits, open slides and open doors, again listing all FST detailed results and data and test design as listed in A immediately above.

C. All details and results of Boeing full scale testing involved with full scale fuel fed fire fuselage tests concerning and confirming proper post –crash operation of all exits, doors and slides, again listing all Applicable and relevant heat flux levels and FST data accumulated
D. Details and results of all Boeing conducted tests concerning survivable cartwheel full scale fuel fed 787 fuselage FST tests including, as ever, heat flux levels, lateral fire spread rates, toxicity analyses and measurements, smoke measurement data, fire ingress, burn through, and all detailed FST test data and results.

Clearly, this demands much Boeing testing, but equally clearly without such tests having been performed, no valid “equivalent level of safety” with respect to the 787 fuselage can be arrived at by the FAA in my opinion.

3.2.4 Review of Improved thermal and Acoustic insulation standards per Section 25.856(b) as cited by Northwest Office FAA Fuselage group in their originating Special Conditions (Ref. 19 and 20)(ref. 21)

The FAA has cited several times the subject standard and I have examined it in some depth as a result. Again, the improvement in such standards is praiseworthy and a clear improvement. However, it is only an incremental improvement and does not address many of the survivable crash scenarios cited in the following section 4 of this of this paper. I quote from the opening statements contained in the final FAA rule as follows:

“The NPRM included the following:
1. A test to measure the propensity of the insulation to spread a fire; and
2. A test to measure the fire penetration resistance of the insulation.”

So clearly, we are discussing in this rule the burn through aspects only and not the FST hazards involved. Specifically, the new thermal/acoustic flammability standards in the final rule do not address, in my reading of it at least, ruptured fuselage survivable crashes, open exits, slides and doors survivable crashes and any cartwheel survivable crashes.

I would quote from this key rule again:

“The improved tests will, however, ensure that the insulation used on airplanes will resist the propagation of fire and thereby reduce the severity of fires and the speed with which fires spread. They will also ensure that insulation the penetration of the airplane from fire from the outside (Author’s note: Again burn through only, not total FST range of hazards is addressed in the rule). These effects will give flight crews additional time to safely land or taxi, as well as giving both passengers and crew more time to safely to safely evacuate the airplane.”

Again, no reference to ruptured fuselages, airplanes with open exits or any FST ingress aspects which are clearly critical to passenger and crew safety prior to safe egress, the failure of the FAA to directly address such a wide range of survivable crashes as proved by past aviation accident history is striking. Such survivable crashes, together with documented survival rates are fully reviewed and illustrated in Section 4 of this
paper. I also note that I have at least two specific examples of past survivable cartwheel crashes (these are detailed in Section 4 of this paper) are cited in Section 4 and therefore the author questions the rejection of by the FAA of complete fuselage improved thermal and acoustic insulation, but rather limiting such improvements to only the lower half of the fuselage. Past crash histories have proven that such cartwheel crashes are survivable. To give an initial specific example, I cite the China Airlines Flight C1642 from Bangkok MD-11 cartwheel crash at Chek Lap Kok airport in Hong Kong on August 22, 1999. To quote from http://dnausers.d.n.a.net this states:

“The jet burst into flames as it flipped upside down and slid down the runway…..killing three people and injuring at least 206. The jet’s right wing dipped and struck the runway, breaking off as the airplane caught fire”

. The cited source continues that there were a total of 315 passengers on board with only three fatalities, so clearly and irrefutably, this was a survivable cartwheel crash, calling into total question the FAA final rule to only apply Sec.25.856(b) improvements to the lower half of half of airplane fuselages.

We also have, in addition the United Airlines Sioux City, Iowa crash July 19th 1989 which also cart wheeled upon crash landing and is listed in Table 1.

In limiting the improvements to only the lower half of the fuselage and in refuting a series of commentator requests to include the entire fuselage the FAA states:

“The FAA has carefully considered whether insulation materials installed in the entire fuselage should have to pass the flame penetration test. As discussed in the preamble to the NPRM, the main issue is that the benefits of such a requirement would be negligible. While a scenario can be envisaged where materials in the upper fuselage would provide a benefit, the conditions would be extremely rare, and were not evident in the benefit study used to develop proposal. For materials in the upper fuselage to be beneficial, the airplane would have to be rolled an extreme amount (by specifying the lower half, the requirement for significant roll), and still be intact. While this scenario may not be far-fetched, there is also post-crash fire for there to be any benefit from the materials. An accident that causes a combination of, no fuselage rupture, but with a post crash fire, is extremely rare if even feasible and is not considered a reasonable basis on which to base a requirement.”

The author believes that the China Airlines MD-11 cartwheel survivable crash thanks to superb piloting skills of the United Airlines pilots, I note, cited Table 1 below both refute the final FAA finding in Ref. 21. I also note that another cartwheel accident will be also cited in detail in the following section, Section 4.

Later in the introductory preamble of the rule, the FAA author states:
“For airplanes with a passenger capacity of 20 or greater, this final rule also requires insulation materials in the lower half of the airplane to pass a test of flame penetration for at least four minutes and must limit the amount of heat that passes through the blanket during the test.”

In reviewing the referenced FAA improved insulation/acoustic standard made effective in September 2003, the author was repeatedly struck by the heavy emphasis by the FAA on burn through as has been discussed. This leads me to the conclusion that, despite FAA protestations to the contrary, that both Boeing and the FAA are focusing on burn through as the prime criteria and possibly as the only basis for fuselage testing. Now, this position can be logically and technically undercut as a premise as follows:

If the FAA and Boeing discuss their certification options re the composite cf/epoxy fuselage (as they traditionally and constantly do with no criticism from me implied) and Boeing convinces the FAA that burn through, not ruptured and open fuselages is to be the primary focus for composite fuselage certification criteria and then the FAA, again, in concert with Boeing, then develops a standard of “Improved Flammability Standards under Sec.25.853 (b), (a), (d)”. And the FAA then finalizes such a burn through based rule and Boeing then tests samples for burn through under such a rule and next Boeing states that, by so doing, it has satisfied all certification standards, then this is clearly a circular argument in terms of logic and in terms, more, importantly, of failing to properly address all required testing concerning FST hazards in all composite new generation fuselages.

Again, this is only a postulation, not a scientific proof, and I can be proved wrong and, I would note, happily so if Boeing has indeed successfully tested all the critical FST survivable crash scenarios that I have listed earlier in this section. I can only hope that Boeing has done so concerning such batteries of full scale tests, but I, together with all the composites aerospace community still await a detailed Boeing engineering response and a detailing of all FST full scale test results upon ruptured cf/epoxy fuselages as well as composite fuselages in down wind situations with open exits, deployed slides and doors and in cartwheel situations.

If Boeing has performed such full scale fuel fed FST tests successfully and submits such detailed test results to the FAA as a potential basis of certification, then that is one answer, but if, instead, Boeing has relied on the final FAA rule discussed above to test only samples of insulation on lower half of fuselage only and uses those tests to claim certification compliance, then this writer has a severe issue with both the FAA and Boeing regarding evading the clear potential FST hazards concerning the 787 composite fuselage structure.

To complete my presentation and FST hazard case, it is necessary to discuss and list past survivable crashes for the reader’s review and such data is presented in Section 4 of this paper.
Section 4. A reviews of survivable crashes and associated published statistics concerning such crashes

A series of reports, statistical studies of survivable crashes for commercial aircraft exists and are regularly updated and I wish to fully recognize and thank the many organizations involved in such efforts. Also the comparatively low passenger fatality rates despite ever increasing traffic, congested airfields, demands upon ATC and fire fighting and rescue teams should and must be recognized and praised. Clearly O.E. M. safety standards are also involved, as are the efforts, AD’s and monitoring by the FAA, the sterling and objective work of National Transportation Safety Board, and such private organizations as the Aviation Safety Network an exclusive service of Flight Safety Foundation (ref. web site www.flightsafety.org) and Air Disaster.com (web site www.airdisaster.com) all provide sterling service concerning survivable and non-survivable crashes, databases and accident records as do the many and various worldwide certificating agencies and outstanding investigative agencies. Finally, I wish to recognize the outstanding performance of so many flight crews and their skilled pilots. All too often, in many past fatal crashes the cause has been determined as “pilot error”. From my perspective and many others in the aerospace community, this is all too clearly, an easy way out and does not do justice to the skills, challenges and sheer courage and professionalism of pilots and flight crews worldwide and I would hope that in the future, more and detailed attention is paid to software errors, coding errors, incorrect assumptions of engineers masquerading as flight laws. I have a problem with the term, flight laws, frankly, which is only a set of engineering assumptions made by the manufacturer. Hence, I must conclude this introduction to Section 4 with a quote from Mr. Bumble in Oliver Twist, namely:

“If the law supposes that, the law is a ass – a idiot. If that’s the eye of the law, the law is a bachelor; ant the worst I wish the law is, that his eye may be opened by experience – by experience.”

Perhaps my patina of age and cynicism is showing, but I would hope that Mr. Bumble’s remarks are taken to heart by engineers making new “flight laws” and I hope that far closer attention is paid, in future, to the prevalence of basic CPU internal and random errors and to the highly sensitive area of software coding mistakes and complex interactions which are increasingly coming to the fore in airplane crashes.

4.1 A Summary of Some Survivable Crashes and Safety Oriented Statistical Reports

From a wealth of such reports, I have chosen four reports for citation in this paper in this paper. The relevant reports are cited as Ref. 22, 23, 24 and 25 respectively. All reports review the survivable aspects of a wide variety of investigated airplane crashes and reach some differing conclusions with respect to survivability. I do not plan to discuss these reports in any detail, but rather will use
them as a factual basis for my subsequent detailed table concerning a wide variety of survivable crashes over the past two decades. I further note that the table (Table 1) as presented below is by no means exhaustive and complete, but rather is intended to clearly illustrate the high survival rates expected and demanded of current commercial airplanes.


The cited report (Ref. 22) is a European report published by the European Transport Safety Council in December 1996 and titled “Increasing the Survival Rate in Aircraft Accidents’ with a sub-title stating the focus of the report, namely “impact protection, fire survivability and evacuation”. This report is thorough and exhaustive in scope and focuses upon Manchester Boeing 737 tragedy with respect to its recommendations. It concludes that approximately 90% of aircraft accidents are categorized as survivable or technically survivable. I think that it is necessary to quote directly from the report introduction at this stage to clarify the premises upon which the report is based for the reader’s review:

Approximately, 90% of aircraft accidents are categorized as survivable (all passengers and crew survive) or technically survivable (where there are some fatalities, but in which some of the passengers or crew survive). In round and, of course, fluctuating figures it is estimated that of the 1500 who die each year world-wide in aircraft transport accidents some 900 die in non-survivable accidents. The other 600 die in technically survivable accidents, where crash-worthiness, fire and evacuation issues are all important. Of these 600 it is estimated that around 330 die as a direct result of impact and 270 due to the effects of smoke, toxic fumes, heat and resulting evacuation problems. Due to the expected rise in the amount of air travel and the density of air traffic, the annual number of deaths may rise further.”

Thus, as an absolute minimum floor at least 270 passengers and crew die on average annually from FST and associated egress problems, based upon the findings of this report. However, we must tread very carefully here regarding our projections and assumptions for the new generation of cf/epoxy composite commercial aircraft fuselages as such untried structures could well drive up considerably the FST death rates cited if FST issues are not clearly addressed and tested for by the manufacturer and certifying agencies. The worst possible outcome for our aerospace industry would be for FST death rates to rise sharply in concert with sharp increases in composite fuselage and wing usage. This is why I am writing and publishing this paper re FST potential hazards at this critical juncture prior to certification of the first of such aircraft, the Boeing 787.

At a later point the report addresses directly the vital need for full scale testing, not sample testing as I have been stressing throughout this extended paper. Specifically in the cited report Sec. 2.5. Testing on page 22 it states:
The need for full scale testing

In order to ensure that the analytical models utilized in design provide an adequate representation of actual crash behavior, full scale tests are required. In addition, the tests provide the opportunity to observe the sequence of events during the crash in great detail due to the availability of extensive instrumentation and a controlled environment.”

In light of the authoritative European foregoing statements plus my rationale stated in detail both in my inputs to the FAA and as discussed in detail herein, it would seem highly advisable for the FAA Northwest Office Fuselage Group to reconsider and hopefully rescind their stated opposition to such full scale tests as cited regarding the crash-worthiness special conditions (Ref. 19 above) plus reconsider only testing insulation samples as discussed also in Section 3.2.4 previously.

On page 10 of the subject European report it states:

“ As the foregoing recommendations suggest, a package of measures is necessary to improve air accident survivability. This comprises:
1. Training of crew and cabin staff to share critical
2. Improving the energy absorbing qualities in the event of an impact
3. Reducing the chance of fire, particularly in the cabin
4. Avoiding the development of toxic fumes
5. Maximizing the opportunities for an orderly and quick evacuation

Clearly this paper is addressing potential FST and fire ingress hazards as the referenced report cites as key factors under items 2, 3, 4, and 5. The EADS “Black Fuselage” research and DLR work on Gondel concepts has been addressing item 2 in their composite fuselage research efforts for the A350 to their credit, but the author does not have any similar Boeing research available to him.

My review of this excellent European report concludes with a sobering warning from the Executive Summary of that report:

For this reason not only the issues concerned with the prevention of the occurrence of accidents, but also issues related to improving the survival rate in the event of an accident will have major importance in the years to come. Failure to take steps now to deal with the increasing exposure to the risk of accident and injury in air travel can only lead to the lowering of current public confidence in air travel.”

These warning words, I hope, are read carefully and weighed closely by Boeing and Airbus engineers and management together with the relevant certifying authorities and by the aerospace engineering community at large.

This NTSB report is cited as Ref. 23 is very extensive, but I note is limited to only U.S. Air carrier operations and not world-wide, thereby we must treat the results with some caution regarding high risk areas outside of the United States. I would note, however, to bolster my case concerning the vital need for full scale ruptured fuselage FST testing, that the report cover has a photograph of a highly ruptured fuselage from an American Airlines DC-9 Survivable accident in Little Rock.

I will not in this paper fully detail all finding of the NTSB report, but clearly this report stands at odds with the previously discussed ETSC report in many areas.

I will summarize the overall NTSB findings as listed on page 21 of their report, again with the caution that is US operators and US accidents only:

1. In all accidents involving Part 121 operations from 1983 through 2000, 51,207 occupants (95.7%) survived while 2,280 occupants died

2. In 528 (93.0%) of the 568 accidents involving Part 121 operations from 1983 to 2000, more than 80% of the occupants survived.

3. In serious Part 121 accidents (those involving fire, serious injury, and other substantial aircraft damage or complete destruction, there were 2739 occupants; 1524 (55.6%) of those occupants survived

4. In 12 (46.2%) of the 26 serious Part 1212 accidents from 1983 through 200, more than 80% of the occupants survived.

5. In serious Part 121 accidents from 1983 through 2000, there were nearly five times more impact fatalities than fire-related fatalities

6. In serious Part 121 accidents from 1983 through 2000 that were categorized as survivable, 1523 of the 1988 occupants (76.6%) survived.

7. In serious Part 121 accidents from 1983 through 2000 that were categorized as survivable, over twice as many occupants died as a result of impact forces than as a result of fire.

8. In 12 (63.2%) of the 19 serious Part 121 accidents from 1983 through 2000 that were categorized as survivable, more than 80% of the occupants survived.

So, in the US alone, over the 18 year period studied by the NTSB a total of 53,487 occupants were involved in accidents both serious and not
serious. That is a large number and whilst high survival rates are cited, for which we are grateful, we must note that all these accidents involved only metallic bodied fuselages and none for cf/epoxy composite fuselages. We must keep this distinction clearly in mind concerning certification issues and fuselage testing. With both the Boeing 787 and the Airbus A350XWB, we are venturing into the unknown with respect to Part 121 Commercial aircraft and we cannot just look back and extrapolate past metallic accident databases forward to unknown composite commercial crash data and this again forces us to examine closely our material selections, FST hazards, auto-ignition hazards during wheels up landings or a multitude of other differences existing between current and past metallic designs and future composite designs as are presently being developed and submitted for certification.

In addition as cited in the NTSB report:

“Passenger enplanements in the U.S. more than doubled in the 16 years following 1983. According to FAA forecast, this growth is expected to continue, approaching one billion enplanements by the year 2010 (an additional 53 % increase)”.

The annual rate of occupants involved in airplane accidents in US carriers only over the past eighteen years was at an average rate of 2971 persons. However, several other factors intrude that increases this annual figure considerably. First, the NTSB only covers USA Part 121 commercial operations and the USA traffic is 2.2 billion annually with the US traffic being 739 million, thus, assuming the absolute best case, which is demonstrably highly optimistic and inaccurate, and using US commercial airlines and FAA regulations and ATC controls only, we arrive at a minimum figure worldwide of 8845 persons annually. Next we must consider traffic growth which is estimated as 53% by FAA by 2010. This increases the best case projected annual persons count involved in commercial aircraft accidents to 13,532 annually by 2010 and if protected rates continue concerning traffic growth, this will again double to 2020 to at least 27064 persons annually. I find such levels of passengers to be involved in aircraft accidents to be disturbing and highly sobering. I would hope and trust that such crash and survival figures receive close scrutiny and assessment and on going safety engineering attention at all levels of O.E.M.s, certificating agencies and relevant airline engineering departments.

A largely composite oriented series of other high risk factors also intrude concerning the new generation of commercial aircraft under discussion, namely:

1. The bulk of the airline traffic growth will come in the Sub-Asian, China, India, Asia, Latin America, the Middle East, ex-Soviet Union bloc countries and Africa. These continents and areas are largely outside the purview of the FAA and have a mixed safety record in some areas as the FAA and NTSB know well.
2. The number of aircraft in commercial 121 service is projected to grow from 7626 in 2006 to 11203 by 2020 per the FAA.

3. The new generation aircraft such as the 787 series and the A350XWB are obviously largely advanced composite demanding new and different skill sets. We all know that composite technology is very thinly spread around the globe as is Quality Assurance, maintenance and repair issues will doubtless arise regarding in-service and operational aspects. Boeing has claimed much lower maintenance levels, typically quoting 40% lower levels. But the question immediately arises as to who is competent, qualified and has the experience and infrastructure to correctly perform such maintenance. Boeing his offering its own Gold Standard” program, presumably designed as a profitable center of expertise. However, recently, when a Qantas subsidiary issued a preliminary RFP concerning 787 maintenance tasks, all quotes, including that of Boeing “Gold Standard,” came in at unacceptably high levels, leaving Boeing to say, rather weakly, in my opinion, that the “Gold Standard” program was “a work in progress”. Fear and inexperience and lack of qualified personnel and sources drive high prices and this is a critical and widely misunderstood area in my opinion.

4. The sharp growth of low cost carriers worldwide is evident and, as an example has reached 50% of US commercial aircraft market share, The same trend is clear worldwide and with emphasis on low cost of entry, low cost operations and lack of previous operational experience this poses a clear additional hazard.

5. Nor are the 787 and A350XWB the only pending composite aircraft with design development afoot at all major makers for A320 series and 737 replacement plus A330 and 767 and 777 replacements also coming and probably will be, for economic, marketing and competitive reasons, designed as basically composite.

Hence I believe that all the foregoing factors would tend to drive up without extremely close monitoring, but the agencies themselves also lack experience. It can be done, but all risks should be soberly and comprehensively addressed by manufactures, agencies and airlines. Let us all be very clear, that it is vital to the health of Boeing and Airbus and indeed our whole industry to address these issues quickly and appropriately. This is no time for either rose colored glasses or listening to the siren songs of marketing departments, but rather it demands a hard- headed safety minded approach and extensive training programs and investments at the airlines ant at the O.E.M.s.
4.1.3 Citation of an FAA Civil Aeromedical Institute (CAMI) titled “CAMI Helps Flyers Survive Aircraft Accidents” FAA Headquarters Intercom March 17th (1998).

I do not have a copy of this specific report and article as cited by the previous NTSB report, but as the NTSB quotes the FAA in their Ref. 23, I have taken to liberty of quoting a review by NTSB on page 5 of their report as follows:

Researchers at FAA examined, in the mid 1990s, a selected set of survivable accidents that occurred from 1970 to 1995 in the United States. Their report was described in the agency’s employee newsletter, the *FAA Intercom*. The researchers found that 68% of occupants involved in aircraft died as a result of injuries sustained during post-crash fires. This number of fire-related fatalities was substantially higher than the ETSC estimates with respect to the proportion of deaths from fire. However, not all accidents that occurred in the study period were included in the FAA analysis.

So, this author concludes that, based upon the foregoing three reports that survivable crashes, fatality rates and causes are still a matter of debate. So this author, bravely or foolishly has decided to illustrate his review of metallic aircraft survivable crashes based upon his own criteria which others are free to agree with or dispute as they so choose.

However prior to so doing I wish to cite an excellent non-governmental source, namely Harro Ranter of Aviation Safety Network. His findings, which are on a world-wide basis, hence rendering more valuable concerning variables concerning a wide range of countries and agencies is presented as Ref. 25 herein. I believe that an objective non-governmental author might well be at least as valuable, and probably more valuable, than governmental agencies which sometimes have their own agendas to present. I have found Mr. Ranter’s reports to be clear, balanced, objective, incisive and well worthy of note and am very grateful for his kindly consenting to use his excellent database in this paper.


As stated above, I greatly admire the research, skill and diligence of Harro Ranter in the Netherlands and his excellent database concerning air safety. Specifically, I wish to quote his analysis concerning average survival percentage per flight phase from the subject report.

On page 14 of his Airliner Accident Statistics 2005 Ref. 25), Harro Ranter lists the following under the general heading of:
**“Average Survival Rate per Flight Phase”**

<table>
<thead>
<tr>
<th>PHASE</th>
<th>2005</th>
<th>1996-2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Takeoff</td>
<td>88.1%</td>
<td>50.1%</td>
</tr>
<tr>
<td>Initial Climb</td>
<td>13.6%</td>
<td>14.1%</td>
</tr>
<tr>
<td>En route</td>
<td>3.3%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Maneuvering</td>
<td>0</td>
<td>31.4%</td>
</tr>
<tr>
<td>Approach</td>
<td>45.2%</td>
<td>17.7%</td>
</tr>
<tr>
<td>Landing</td>
<td>69.9%</td>
<td>82.0%</td>
</tr>
<tr>
<td>Unknown</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>29.4%</strong></td>
<td><strong>25.9%</strong></td>
</tr>
</tbody>
</table>

I have chosen to adopt the right hand ten year period to smooth the large year to year fluctuations as is the case in aircraft safety. Thus I arrive at an overall average figure for all flight phases as 25.9% survival rate. However, for the critical from an FST hazard viewpoint, I have selected landing and takeoff as the two major indicators and these are 50.1 and 82% respectively. Averaging these two events, we arrive at an average survival rate for these two phases of 66% survival rate, which is less than the NTSB estimates and more than the cited FAA report, so I believe that we are on safe middle ground here.

Finally, after receiving his kind consent to cite and use his materials, I wish to present Mr. Ranter’s excellent presentation putting 2002 in a historical perspective (Fig. 35) and his historical review of accident rates for jets, piston aircraft and prop-jets as presented in Fig: 36. I hope that these prove of interest to the reader. The downward trend in accidents over the years is encouraging although one finds less solace if we examine to period from 1983 to 2002 where the accident rate remained on a plateau of sorts with no clear direction evident. This is also evident from Mr. Ranter’s Fig 36 where the jet rate stays close to flat over the 1983 to 2002 period. From this we can draw a tentative conclusion that jet commercial aircraft aren’t getting worse, but conversely, they aren’t getting any better in terms of accident rates.

And again, I must caution the reader against projecting past metallic survivability rates from the past into the future where new generation and unproven in-service to date composite fuselages and aircraft are concerned.
2002 IN HISTORICAL PERSPECTIVE

- The 2002 death toll of 1098 was below the 1972-2001 average death toll of 1445 casualties
- The 2002 death toll of 1098 was below the 1992-2001 average death toll of 1293 casualties
- The 2002 number of occupants involved in fatal airliner accidents of 1335 was lower than the 1992-2001 average of 1762
- The 2002 fatality rate (percentage of occupants killed in fatal airliner accidents) of 82% was higher than the 1992-2001 average of 73%
- The 2002 number of 37 fatal airliner accidents was far below the 1972-2001 average number of fatal airliner accidents of 50.7 per year
- The 2002 number of 37 fatal airliner accidents was far below the 1992-2001 average number of fatal airliner accidents of 47 per year

![FIG. 35](image)

- The 2002 number of fatal jet airliner accidents of 12 was below the 1972-2001 average of 16.7 accidents per year
- The 2002 number of fatal prop airliner accidents of 23 was on the 1972-2001 average of 23.3 accidents per year
- The 2002 number of 1 fatal piston airliner accident was far below the 1972-2001 average of 10.4 accidents
- The 2002 number of 1 fatal piston airliner accident was far below the 1992-2001 average of 5 accidents

![Fig. 36](image)
Section 4.1.5 A selected tabulation and series of illustrations of survivable aircraft crashes

Here we come to the final points concerning potential FST hazards as cited above and I have used as my major sources two well respected organizations, namely Mr. Harro Ranter’s Air Safety Network (www.aviation-safety.net) as cited above as ref. 25, http://dnausers.d-n-a.net (Ref. 27) and www.airdisaster.com (Ref. 26), all three of which meticulously document and establish wide ranging accident data bases together with providing an excellent range of survivable accident photographs which I will also employ in this final section.

As discussed earlier there are many different criteria which can be employed concerning survivable crashes and I have chosen as my criteria for this paper the following concerning defining a survivable crash. I will use as my criteria, that at least 20% of the passengers survive the crash.

In addition, given my paper’s FST hazard focus, I have selected from such designated survivable crashes, that the fuselage must ruptured or pierced thereby defeating the improved thermal/acoustic insulation rule promulgated and finalized by the FAA. Such ruptures or fuselage piercing clearly defeat any lower half of the fuselage FAA dictated insulation improvements and allow immediate potentially fatal ingress of FST products into the passenger compartment. My survivable crash selection is clearly a subset of all survivable crashes, but there are a host of such examples choose from and cite and my table below is by no means complete, I have merely selected enough to emphatically prove my point to the reader. I have also included a few freighter crashes as they are deemed appropriate to the FST and ruptured fuselage aspects of this paper. Please also, there is not a one-to-one correlation of table items to the accompanying photographs, 1 through 38, but the intent is to demonstrate comprehensively and I would hope fairly irrefutably that there exist a very extensive history of survivable crashes occurring both on takeoff or landing phases, which include ruptured and penetrated fuselages, opened exits and deployed slides and flip-overs or cartwheels calling into serious question any certification or development that does not include a wide-ranging series of full scale tests closely replicating such past survivable accidents as called for earlier in this paper.

This is key area, of course, as if Boeing and FAA use only or largely use primarily burn through criteria of the composite fuselage for certification, I have, in turn to show and prove that a large number of survivable crashes result in ruptured fuselages. I hope my position is both clear and logical, namely that in many survivable crash situations, fuselages are broken, compromised, ruptured or penetrated thereby rendering burn through and insulation tests irrelevant and fallacious.

In a similar FST hazard scenario, even if the fuselage is not ruptured or penetrated, to ask large, deathly frightened, panicked and inexperienced passengers crowded into high capacity compartments to just sit and watch external surrounding fuselage fires for five minutes of more is clearly without doing anything is a ridiculous and unfeasible scenario. Just as in many previous fuel fed fire survivable crashes as clear from both the 11985 Boeing 737 and the more recent A340 overrun accident at Malton as evidenced by the relevant accident reports passengers and cabin crew will attempt to
escape fro all available exit doors and overwing exits. Thus exits will be opened, slides deployed and doors opened as passengers make desperate last efforts to save their lives. This scenario in turn allows ingress of FST products into the passenger compartment from the external composite fuselage fire. Finally, it appears from the Manchester crash report that windows can expect to last around two minutes, again allowing ingress of toxic products and dense smoke into the passenger cabin.

In the next scenario, wheels up landings are clearly expected to be fully survivable in the absence of any fuselage rupture or fuselage penetration. However, the low auto-ignition temperatures of epoxies in the 580 degrees F area and at levels 1200 degrees F lower than aluminum ignition levels demands full scale testing also to assess all potential ignition risks.

Finally, some cartwheel survivable crashes have occurred over the past decade in large Part 121 commercial aircraft and doubtless will again and if the latest FAA thermal insulation/ acoustic standard cited and discussed earlier is not upgraded to include the entire fuselage, then again, passengers are put at risk and another severe potential FST hazard exists. These four key FST hazardous scenarios are all included in Table I and I would hope provide ample data and information for the aerospace composites community and, hopefully, lead to concurrence by my engineering peers concerning new generation composite fuselage FST hazards.
Table 1
A Listing of selected Survivable Accidents all involving; Opened, Ruptured, Penetrated or Otherwise Compromised Fuselages

Updated June 2010

<table>
<thead>
<tr>
<th>Accident Date &amp; AC type</th>
<th>Airline/ Flt. No.</th>
<th>Location</th>
<th>Total Occupants</th>
<th>Fatalities</th>
<th>Percentage Survivability Rate</th>
<th>Source credit and photo credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>09/14/1999 757-204</td>
<td>Britannia BY226A</td>
<td>Gerona, Spain</td>
<td>247</td>
<td>1 ??</td>
<td>100%</td>
<td><a href="http://dnausers.d-n-a.net">http://dnausers.d-n-a.net</a></td>
</tr>
<tr>
<td>05/08/1997 737-31B</td>
<td>China Southern CZ 3456</td>
<td>Chonqing, Sichuan</td>
<td>74</td>
<td>35</td>
<td>53%</td>
<td><a href="http://dnausers.d-n-a.net">http://dnausers.d-n-a.net</a></td>
</tr>
<tr>
<td>10/29/1996 747</td>
<td>Tower Air 41</td>
<td>JFK Airport</td>
<td>468</td>
<td>0</td>
<td>100%</td>
<td><a href="http://dnausers.d-n-a.net">http://dnausers.d-n-a.net</a></td>
</tr>
<tr>
<td>03/22/92 F-28-4000</td>
<td>USAir</td>
<td>Flushing, NY</td>
<td>51</td>
<td>27</td>
<td>47%</td>
<td><a href="http://dnausers.d-n-a.net">http://dnausers.d-n-a.net</a></td>
</tr>
<tr>
<td>09/16/2007 MD-82</td>
<td>One-Two-Go by Orient Thai OG269</td>
<td>Phuket, Thailand</td>
<td>130</td>
<td>88</td>
<td>32%</td>
<td><a href="http://airdisaster.com">http://airdisaster.com</a></td>
</tr>
<tr>
<td>12/18/2003 MD MD-10-10F</td>
<td>Federal Express</td>
<td>Memphis, Tenn.</td>
<td>7</td>
<td>0</td>
<td>100%</td>
<td><a href="http://airdisaster.com">http://airdisaster.com</a></td>
</tr>
<tr>
<td>Date</td>
<td>Airline/Model</td>
<td>Location</td>
<td>Passenger Count</td>
<td>Fatalities</td>
<td>Survival Rate</td>
<td>Source</td>
</tr>
<tr>
<td>------------</td>
<td>---------------</td>
<td>--------------------</td>
<td>-----------------</td>
<td>------------</td>
<td>---------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>02/08/2005</td>
<td>Air France</td>
<td>Toronto, Canada</td>
<td>309</td>
<td>0</td>
<td>100%</td>
<td><a href="http://airdisaster.com">http://airdisaster.com</a></td>
</tr>
<tr>
<td>12/08/2005</td>
<td>Southwest Airlines</td>
<td>Midway Airport, Chicago</td>
<td>103</td>
<td>1 ground</td>
<td>100%</td>
<td>NTSB file number 22717</td>
</tr>
<tr>
<td>08/24/1999</td>
<td>Uni Airlines</td>
<td>Haulien, Taiwan</td>
<td>96</td>
<td>0</td>
<td>100%</td>
<td><a href="http://airdisaster.com">http://airdisaster.com</a></td>
</tr>
<tr>
<td>08/31/1999</td>
<td>Lineas Aereas Prividas Argentinas</td>
<td>Buenos Aires, Argentina</td>
<td>103</td>
<td>79</td>
<td>23%</td>
<td><a href="http://airdisaster.com">http://airdisaster.com</a></td>
</tr>
<tr>
<td>08/22/1999</td>
<td>China Airlines</td>
<td>Hong Kong</td>
<td>315</td>
<td>3</td>
<td>99%</td>
<td><a href="http://airdisaster.com">http://airdisaster.com</a></td>
</tr>
<tr>
<td>06/01/1999</td>
<td>American Airlines</td>
<td>Little Rock, AK</td>
<td>143</td>
<td>12</td>
<td>92%</td>
<td><a href="http://airdisaster.com">http://airdisaster.com</a></td>
</tr>
<tr>
<td>03/29/1999</td>
<td>Korean Airlines</td>
<td>Pohang, South Korea</td>
<td>156</td>
<td>0</td>
<td>100%</td>
<td><a href="http://airdisaster.com">http://airdisaster.com</a></td>
</tr>
<tr>
<td>03/05/1999</td>
<td>Air France</td>
<td>Madras, India</td>
<td>5</td>
<td>0</td>
<td>100%</td>
<td><a href="http://airdisaster.com">http://airdisaster.com</a></td>
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<tr>
<td>Date</td>
<td>Airline</td>
<td>Aircraft Type</td>
<td>Flight No</td>
<td>Location 1</td>
<td>Location 2</td>
<td>Details</td>
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<td>--------------------------------</td>
<td>---------------------</td>
<td>-----------</td>
<td>---------------------</td>
<td>---------------------</td>
<td>---------</td>
</tr>
<tr>
<td>05/08/1998</td>
<td>Korean Air Lines</td>
<td>747-4B5</td>
<td>Flt. 8702</td>
<td>Seoul, South Korea</td>
<td></td>
<td>395</td>
</tr>
<tr>
<td>09/16/1998</td>
<td>Continental Airlines</td>
<td>737-524</td>
<td></td>
<td>Guadalajara, Mexico</td>
<td></td>
<td>108</td>
</tr>
<tr>
<td>11/16/2007</td>
<td>Airbus</td>
<td>A340-642</td>
<td></td>
<td>Blagnac, Toulouse</td>
<td>(pre-delivery to</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Etihad)</td>
<td></td>
</tr>
<tr>
<td>07/30/1992</td>
<td>TWA</td>
<td>L-1011</td>
<td>Flt. 843</td>
<td>JFK Airport</td>
<td></td>
<td>280</td>
</tr>
<tr>
<td>10/31/2000</td>
<td>Singapore Airlines</td>
<td>747-412</td>
<td></td>
<td>Taipei, Taiwan</td>
<td></td>
<td>179</td>
</tr>
<tr>
<td></td>
<td></td>
<td>McD DC-10-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07/19/1989</td>
<td>United Airlines</td>
<td>McD DC-10-10</td>
<td></td>
<td>Siberia, Russia</td>
<td></td>
<td>298</td>
</tr>
<tr>
<td>09/13/1982</td>
<td>Spantex</td>
<td>McD DC-10-30</td>
<td></td>
<td>Malaga, Spain</td>
<td></td>
<td>393</td>
</tr>
<tr>
<td>03/17/2007</td>
<td>UTAir</td>
<td>TU-134A</td>
<td>Flt. 471</td>
<td>Samara, Russia</td>
<td></td>
<td>57</td>
</tr>
<tr>
<td>07/12/2000</td>
<td>Hapag-Lloyd</td>
<td>A310-304</td>
<td></td>
<td>Vienna, Austria</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>05/11/1990</td>
<td>Philippine Airlines</td>
<td>B737-3Y0</td>
<td></td>
<td>Manila, Philippines</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>10/26/2007</td>
<td>Philippine Airlines</td>
<td></td>
<td></td>
<td>Butuan, Philippines</td>
<td></td>
<td>154</td>
</tr>
<tr>
<td>Date</td>
<td>Airline</td>
<td>Model</td>
<td>Origin/Location</td>
<td>Passengers</td>
<td>Injuries</td>
<td>Fatality Rate</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
<td>-------</td>
<td>-----------------</td>
<td>-------------</td>
<td>-----------</td>
<td>---------------</td>
</tr>
<tr>
<td>08/26/2007</td>
<td>China Airlines</td>
<td>A320-214</td>
<td>Naha, Okinawa</td>
<td>165</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>07/30/2008</td>
<td>Eclipse Aviation</td>
<td>Eclipse 500</td>
<td>West Chester-Brandywine</td>
<td>2</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>08/03/2008</td>
<td>ANA</td>
<td>B747 (Maintenance)</td>
<td>Bangkok, Don Muang Airport</td>
<td>workers</td>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>09/22/2008</td>
<td>ICARO</td>
<td>Fokker Friendship 4000</td>
<td>Quito-Marsscal Airport</td>
<td>0</td>
<td>66</td>
<td>100%</td>
</tr>
<tr>
<td>01/10/2008</td>
<td>KD Avia</td>
<td>B737-3YO</td>
<td>Kalingin-grad-Khrabrovo Airport</td>
<td>0</td>
<td>144</td>
<td>100%</td>
</tr>
<tr>
<td>16/10/2008</td>
<td>Rutaca</td>
<td>B737-2H4</td>
<td>Caracas Simon Bolivar Airport</td>
<td>0</td>
<td>54</td>
<td>100%</td>
</tr>
<tr>
<td>10/11/2008</td>
<td>Ryanair</td>
<td>B737-8AS</td>
<td>Rome</td>
<td>0</td>
<td>172</td>
<td>100%</td>
</tr>
<tr>
<td>10/11/2008</td>
<td>Veteran Airlines</td>
<td>Ant 12B</td>
<td>Pointe Noire Airport Cambridge</td>
<td>0</td>
<td>Unk.</td>
<td>100%</td>
</tr>
<tr>
<td>12/13/2008</td>
<td>Summit Air</td>
<td>Dornier</td>
<td>Bay Airport, NU,Canada</td>
<td>0</td>
<td>14</td>
<td>100%</td>
</tr>
<tr>
<td>Date</td>
<td>Aircraft</td>
<td>Operator</td>
<td>Departure</td>
<td>Arrival</td>
<td>Survival</td>
<td>Link</td>
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<tr>
<td>------------</td>
<td>----------</td>
<td>----------------------</td>
<td>-----------</td>
<td>-----------</td>
<td>----------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>12/20/2008</td>
<td>B737-524</td>
<td>Continental Airlines</td>
<td>Denver Inter. Airport</td>
<td>0</td>
<td>115</td>
<td>100% <a href="http://air-safety.net">http://air-safety.net</a></td>
</tr>
<tr>
<td>1/20/2009</td>
<td>Bombardier Global 500</td>
<td>Bombardier</td>
<td>Wichita-Midway Airport</td>
<td>standing</td>
<td>0</td>
<td>100% <a href="http://air-safety.net">http://air-safety.net</a></td>
</tr>
<tr>
<td>1/27/2009</td>
<td>ATR-42-320</td>
<td>Empire Airlines (op. For FEDEX)</td>
<td>Lubbock Preston Smith Airport</td>
<td>0</td>
<td>3</td>
<td>100% <a href="http://air-safety.net">http://air-safety.net</a></td>
</tr>
<tr>
<td>1/27/2009</td>
<td>Cessna 560 Citation</td>
<td>Tyrol Air Ambulance</td>
<td>Novosibirsk Tolmachevo Airport</td>
<td>0</td>
<td>4</td>
<td>100% <a href="http://air-safety.net">http://air-safety.net</a></td>
</tr>
<tr>
<td>2/12/2009</td>
<td>Bae 3102 Jetstream</td>
<td>Sky Express</td>
<td>N. kazantzakis Airport</td>
<td>0</td>
<td>18</td>
<td>100% <a href="http://air-safety.net">http://air-safety.net</a></td>
</tr>
<tr>
<td>2/13/2009</td>
<td>AVRO RJ 100</td>
<td>B.A. City Flyer</td>
<td>London City Airport</td>
<td>0</td>
<td>71</td>
<td>100% <a href="http://air-safety.net">http://air-safety.net</a></td>
</tr>
<tr>
<td>Date</td>
<td>Airline</td>
<td>Aircraft Type</td>
<td>Departure Airport</td>
<td>Arrival Airport</td>
<td>Passengers</td>
<td>Deaths</td>
</tr>
<tr>
<td>------------</td>
<td>------------------------</td>
<td>-----------------</td>
<td>-------------------------</td>
<td>-----------------------</td>
<td>------------</td>
<td>--------</td>
</tr>
<tr>
<td>4/27/2009</td>
<td>Magni-Charters</td>
<td>B737</td>
<td>Guadalajara Airport</td>
<td>0</td>
<td>116</td>
<td>100%</td>
</tr>
<tr>
<td>5/6/2009</td>
<td>World Airways</td>
<td>DC-10</td>
<td>Baltimore-Washington Airport</td>
<td>0</td>
<td>180</td>
<td>100%</td>
</tr>
<tr>
<td>05/8/2009</td>
<td>Saudia</td>
<td>MD-90-30</td>
<td>Riyadh-King Kalid Airport</td>
<td>0</td>
<td>8</td>
<td>100%</td>
</tr>
<tr>
<td>05/30/2009</td>
<td>PIA</td>
<td>ATR-42-500</td>
<td>Lahore Airport</td>
<td>0</td>
<td>43</td>
<td>100%</td>
</tr>
<tr>
<td>06/02/2009</td>
<td>Kenn-Burek</td>
<td>DHC-6 Twin Otter</td>
<td>Halaveli Island Resort</td>
<td>0</td>
<td>7</td>
<td>100%</td>
</tr>
<tr>
<td>06/06/2009</td>
<td>Myanmar Airways</td>
<td>Fokker F-28 Friendship</td>
<td>Sittwe Civil Airport</td>
<td>0</td>
<td>68</td>
<td>100%</td>
</tr>
<tr>
<td>06/26/2009</td>
<td>TAC</td>
<td>LET-410-UVP-E</td>
<td>Capureana Airport</td>
<td>0</td>
<td>21</td>
<td>100%</td>
</tr>
<tr>
<td>07/13/2009</td>
<td>Southwest Airlines</td>
<td>B737-3H4</td>
<td>Diverted to Charleston-Yeager</td>
<td>0</td>
<td>131</td>
<td>100%</td>
</tr>
<tr>
<td>Date</td>
<td>Airline</td>
<td>Aircraft Model</td>
<td>Airport</td>
<td>Fatalities</td>
<td>Injuries</td>
<td>OLI</td>
</tr>
<tr>
<td>------------</td>
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<td>----------------------</td>
<td>----------------------------------</td>
<td>------------</td>
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</tr>
<tr>
<td>07/24/2009</td>
<td>Ilyushin 62</td>
<td></td>
<td>Mashhur Airport</td>
<td>16</td>
<td>153</td>
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<td>08/04/2009</td>
<td>Bangkok Airlines</td>
<td>ATR 72-212A</td>
<td>Koh Sumui Airport</td>
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<tr>
<td>09/24/2009</td>
<td>Bae 4121 Jetstream</td>
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<tr>
<td>10/15/2009</td>
<td>Blue Wing Airlines</td>
<td>Ant 28</td>
<td>Kwamala-samutu Airfield</td>
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</tr>
<tr>
<td>11/9/2009</td>
<td>Blue Bird Airlines</td>
<td>Beechcraft 1900D</td>
<td>Mogadishu Airport</td>
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<td>11/10/2009</td>
<td>Kingfisher Airlines</td>
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<td>Mumbai Airport</td>
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<td>Rwanda Express</td>
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<td>Kigali Airport, Rwanda</td>
<td>1</td>
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<td>TAF Linhas</td>
<td>B727-222F</td>
<td>Sao Paulo Airport</td>
<td>0</td>
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<td>Date</td>
<td>Airplane</td>
<td>Carrier</td>
<td>Airport</td>
<td>Fatalities</td>
<td>Injuries</td>
<td>Survival Rate</td>
</tr>
<tr>
<td>------------</td>
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<td>-------------------</td>
<td>---------------------------</td>
<td>------------</td>
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</tr>
<tr>
<td>12/07/2009</td>
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<td>Aereas S. A.</td>
<td>George Airport</td>
<td>0</td>
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</tr>
<tr>
<td></td>
<td>RJ135LR</td>
<td>Airlink</td>
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<tr>
<td>01/10/2010</td>
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<tr>
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As stated earlier, this list of accidents is not inclusive by any means, but only represents a sampling of survivable accidents and crashes. I feel it necessary to present such a wide-ranging list to fully substantiate my position that in many survivable crash situations, ruptured fuselages accompanied by fuel-fed fires which eventually destroyed the aircraft are commonplace in our industry rather than being the exceptions. When planes overshoot, undershoot, land too hard or collide with ground objects, they break into several parts with respect to their fuselages or are penetrated by external wing, ground objects, empennages, engines or other structures. This is clear and evident history and this vulnerability can only grow worse if CF/epoxy fuselages with their proven unacceptably high FST levels are employed in the new generation large and small commercial aircraft of which the Boeing 787 is closest to EIS and certification. This situation eliminates, in my opinion, any improvements in such cases stemming from enhanced lower half thermal/acoustic insulation for the fuselage as has been proposed and finalized by the FAA. Clearly, ruptured fuselages, cart-wheel or flip-overs, and opened exits and slides allow ingress of critical FST products into the passenger compartment thereby threatening the lives and safe egress of passengers and crew. And the past history, further, cannot be projected into the future, given the far lower ignition temperatures for the epoxy fuselage structure. Our industry must address these issues clearly and decisively or clearly heightened passenger safety risks from FST.
Unless Boeing and Airbus, by a series of actual, not simulated, conduction of full scale fuel fed ruptured fuselage and downwind open exits and doors full scale fuselage fire tests can prove to the peer composites community that the FST hazard either does not exist or at very low and acceptable levels, these areas represent a serious and even critical safety situation which demands appropriate FST test programs prior to any certification being contemplated by the O.E.M.s and responsible certifying agencies. Similarly, full scale tests simulating wheels up landings are vital to assess the dangers inherent in epoxy matrices for commercial airplanes.

Obviously Boeing, Airbus and other manufacturers have whole departments culling and studying such survivable accident reports as do the NTSB and FAA and EASA along with many other agencies, and I would urge them all to conduct a wide-ranging investigation of all past accidents and then measure the proposed series of FST full scale test programs against such a database for validity, applicability and correct D.O.E.

I am obviously not asking for crash proof airplanes or 100% survival rates as that position would be foolish and unattainable, but the public should be assured and have demonstrated to them by both O.E.M.s and the certifying agencies that the new generation of large, commercial aircraft clearly are advances in passenger safety regarding FST hazards and not a retreat from present metallic based safety standards.

Finally, let me be very clear in my position, I am not appealing, preaching, exhorting or proselytizing in this paper. I have, I hope, presented the high FST risks case in a logical and objective engineering manner, by citing and examining ample evidence to prove the clear FST risks concerning epoxy fuselages, followed by a detailed review of current lack or any FAA standards for external composite fires, then by citing the present burn through oriented proposed FAA and Boeing certification approach rather than addressing the FST risk issue as a whole. Finally, I have linked such FST and ruptured fuselage risks and fires to an extensive tabulation of a wide range of survivable accidents or incidents to substantiate that ruptured fuselages or open doors, slides, exits and fires are the expected scenarios for landing and take off flight phases. I leave it to my peers in composites to now openly and responsibly debate and test for such risks.

My engineering position is the faster we can get rid of epoxies for primary structures on commercial aircraft, the better it will be for our aerospace industry and for the traveling public. Clearly, there are potential and far safer from FST risk standpoint in development or available as discussed earlier and cyanate esters such as various PT15 formulations based upon their phenolics chemical backbones and excellent proven low FST levels, plus certain thermoplastics if they can be made cost competitive. Obviously such changed matrices with excellent FST properties must also possess acceptable HCN and toxicity levels and smoke properties also.

I am presenting below a selected photographs showing the risks passengers and crew face in survivable crashes and as evidence of ruptured fuselages, penetrated fuselages and post crash fires as documented proofs that my composite engineering peers can independently. I do not do this to shock or to dwell
upon the tragic side here, but I believe my fellow composite engineers will benefit
from reviewing this wide range of photographic evidence. We, as an aerospace
industry, can be proud of such high survival rates in metallic aircraft and I hope that
your review leads us to achieve equal or far better survivability standards, but that
will take and great deal of testing, verification and close attention to all the new
challenges which face us. We all want success for both the Boeing 787 and Airbus
A-350XWB and their composite based successors, but to do that we must identify,
test for and assure ourselves that we have minimize the risks concerning composites
also.

. Finally, I wish to again thank the three excellent web-based
data bases referenced earlier and we can all be very grateful for their superb efforts,
dedicated research and careful documentation.

Section 5

Final Remarks

At this juncture, normally in papers such as this, there usually
appears: “Results and Conclusions’ or “Conclusions and Recommendations” and, if the
author is a university researcher looking for more funds, will additionally stress the
necessity for more funded research. In this case, I am not looking for governmental funds
or any funds to perform research, but rather am presenting the results of my work and
those of research experts in the FST field bolstered by many examples of ruptured or
penetrated commercial aircraft fuselages both with fuel fed fires and without. The clear
and present FST fuselage risks concerning usage of cf/epoxy in the new generation of
commercial aircraft are, I believe, amply documented in Section 2 of this paper while a
detailed tabulation and illustrations of a wide series of survivable commercial aircraft
crashes are presented in Section 4 to substantiate the frequent occurrence of ruptured and
penetrated fuselages in such incidents. I further believe that the previous cited sections
and other background data pertaining to FST hazards clearly and logically leads to the
prime conclusion that major potential FST hazards exist for cf/epoxy fuselages which, in
my opinion, places the onus upon Boeing to conduct a series full scale fuel fed FST 787
tests on both ruptured fuselages and upon fuselages with penetrated and open down wind
exits as a matter of public policy and for passenger safety reasons. Further, I would urge
the FAA to fully incorporate and closely review the results of such tests for validity and
accuracy prior to certification of the 787 aircraft.

I have, over the past two years, performed much research and have
concluded, to my satisfaction at least, as cited earlier in this paper, that a major potential
FSA hazard exists on the new generation of commercial airplanes and, as the Boeing 787,
is clearly first in line for certification, I am focusing the bulk of my remarks towards
Boeing and the 787 series aircraft. This does not exclude the Airbus A350XWB, of
course, but clearly the most urgency must, both by certification challenges, schedule and
EIS, is upon Boeing.

In similar fashion I have tried on many occasions via formal and
informal inputs and contacts to convince the Northwest office of the FAA to act in this
matter. I have failed to this point due to, quite possibly, to my poor powers of persuasion or lack of obsequiousness. However, in so doing, I have developed some excellent relationships at that agency and am particularly grateful to Mr. Dostert and Dr. Ilcewicz for their outstanding cooperation, discussions and insights. However, the FAA fuselage group specifically appears to be going the route of “equivalent level of safety” (yet to be published) and by a focus on burn through, which is only represents a narrow interpretation of the total FST hazard scenario, and via “encouraging Boeing to meet a standard” rather than requiring such full scale FST tests as I would expect in light of the extensive FST hazards detailed in this paper. I find this current direction at FAA to be deeply troubling.

Now, in terms of scientific proof, I can only turn to Scottish law and their tradition of three verdicts regarding the overall FST risks involved in the new generation of large commercial airplanes with composite fuselages and wings. Based upon Section 2 and its detailed references, the writer reaches at least a verdict of not proven and possibly guilty regarding the FST hazards posed by epoxies. In a “not proven” verdict the preponderance of evidence points to guilty, but in clear absolute scientific terms, guilty could be judged as too harsh. I believe that in terms of any adverse impact to passenger safety for the new generation of composite fuselages that again we are in a “scientific” not proven arena. In this statement, I can only cite the preponderance of evidence implicating FST as a serious hazard, but, lacking any details of Boeing conducted full scale fuel fed FST fuselage testing in the literature, only “not proven” verdict in scientific terms is again valid. Engineering frequently operates in such gray areas and in terms of probability, so we can only await the details of all relevant Boeing FST tests, their scope, and their validity for peer review to be published prior to certification.

I further feel that in the key issue concerning primary structural external composites FST fires and risks at the Northwest office of FAA is well meaning and dedicated, but is often heavily reliant upon Boeing development test inputs and data. However, regarding FST full scale ruptured or penetrated fuselage FST test results, to date Boeing has hardly been forthcoming either with the FAA as cited earlier and certainly not with the outside composites engineering community.

With respect to lack of regulations and standards concerning external composite fires, one suspects a combination of lack of funding, limited composites expertise until recently or some bureaucratic inertia and not having all the governmental personnel available widely skilled in composites as would be ideal. This is certainly not intended to disparage nor demean the work of the FAA in any manner whatsoever, but rather, a facing of the facts by the writer after three rejections of my formal inputs to FAA published FST and fire and crash oriented Special Conditions and in spite of consistent agreement by the FAA that FST is a critical safety issue, but always finally adding “out of scope” in casting my formal inputs and data into the outer darkness. These refusals to invoke a Special Condition for such full scale FST tests by the FAA leaves the author with little hope of change of heart at the FAA prior to any 787 certification. In addition, the FAA has stated to me that they have done no FST full scale testing on the current 787 composite fuselage materials, but are awaiting Boeing’s own results. I can live in hope re a possible FAA change of heart after their review of this paper and its supporting data, but that hope is very high at present.
I further wish to include in my final remarks to cite the NASA Boeing 720 crash tests in California some years back. As many in the community know, a UK chemical company back then claimed to have a chemical inerting solution to suppress wing fuel tank fires. Much marketing and debate ensued, but NASA, very wisely, in my opinion, over much criticism re the cost of the test, decided to simulate a survivable crash test on a full scale aircraft in the California test using the inerting chemical claimed solution to all fuel tank fire ills. The resulting huge explosion and fire cut through all the debate and clearly demonstrated that the claims were totally invalid. There are parallels to be drawn between that earlier NASA test and the present potential FST hazard situation and I would request that the FAA review their present rejection of full scale FST tests once again.

Clearly, the FAA is an excellent and highly dedicated agency and they have enforced rigorously and well the regulations and standards concerning cabin interiors over the decades stemming from the 1970’s research which clearly defined the epoxy FST issue. However, regarding external composites the FAA has established no regulations and standards concerning post crash survivable crashes involving ruptured fuselages, open slides and exit doors down wind other than the upgrading of lower fuselage thermal insulation under the aegis of FAR 25.256(b) as detailed in Section 3 of this paper. This incremental improvement is praiseworthy and worthy of note, but this is a limited response, at best, and does not address the overall FST external fire fuselage problem facing both Boeing and Airbus. I think that it will take some time for FAA to set required standards and regulations and move decisively re enforcement in this area, just as it took some time to develop, change and enforce the 1970’s era interior cabin standards. Hence, I choose to address these final closing remarks largely towards the dedicated engineers at Boeing in large measure with natural and inclusive extension to Airbus and its equally talented cadre of engineers.

I conclude by urging and requesting that Boeing engineers examine and reexamine their own internal tests re FST fuel fed full scale testing and determine if they are fully satisfied regarding improved passenger egress and lower FST hazards. Can Boeing engineering totally and satisfactorily answer the interim conclusions reached and the questions posed at the end of Section 2 of this paper? Further, as I am no genius or oracle, am I missing something or data (the dreaded unk-unks again) that has arisen during the course of Boeing’s internal developmental testing? This is not an appeal, but rather an exhortation and statement to all concerned 787 Boeing engineers and their management to examine and reexamine their own data carefully, recheck that the full scale fuel fed FST of ruptured fuselages and open slides and exits has been adequately tested and that they are fully and professionally satisfied with the results. Equally, are Boeing’s structural, design, test and composite engineers fully convinced of validity, accuracy and scope of the development tests performed and are not merely relying on a single aspect, namely burn through or on a very limited FAA upgrade via FAR 25.256(b) as a basis of certification?

Also, let me make my position very clear regarding the vital need for full scale fuel fed fire FST testing for the 787-8. Engineers do not test for mere sake of testing, nor to waste valuable company and program resources. Engineers test because analysis alone or previous aircraft experience and database do not give them sufficient
confidence of composite fuselage performance in this case for ruptured or penetrated fuselages in survivable crashes. Further, engineers do not test down to an FAA regulation or lack of it, but rather test up to a professional and highest safety standard to give them sufficient confidence and assurance that the predicted behavior aircraft matches or exceeds analytical and design predictions. We do “worst case, but Survivable testing in all areas or we are derelict in our responsibilities and duties to the aircraft industry and the traveling public. There should be no argument on this point from many responsible engineers and certifying authorities. When in doubt, perform a full-scale test is clearly the aerospace engineer’s creed and for this reason alone, I take strong issue with the FAA fuselage group’s final finding in Docket Number Special Condition NM368, No. 25-362-SC dated 9-25-2007 which states:

“While there are merits in conducting a full-scale test, there are other approaches using test and analysis that can actually yield more data than would a single test. Thus, we consider it effective to establish the standards and encourage (my emphasis added) the applicant to develop the most effective method of compliance”.

The foregoing FAA statement appears to fly in the face of all normal aerospace engineering practice, in my opinion, and also exhibits a logical contradiction to the FAA’s own standard demand and requirements for both static and fatigue tests to certify all new commercial aircraft. Clearly, all aircraft in service experience an almost infinite set of fatigue scenarios, just as there are a huge set of flight load cases, but the FAA never retreats to “encouraging the applicant to develop the most effective method of compliance” in such cases. Instead the FAA requires and mandates such fatigue and static tests as being conditions required to meet FAR 121 requirements for all commercial aircraft without exception and these requirements have been set up as a matter of public policy safety concerns and the experience gained over decades of past crashes. Thus, I must strongly refute the FAA’s stated position in not enforcing a series of full scale FST ruptured or penetrated fuel fed fuselage tests for the 787 aircraft upon the applicant, but “leaving it up to the applicant to develop the most effective method of compliance”. Again, the whole certification process and its associated requirements are and must always be founded upon passenger safety as both the FAA Mission and the NTSB report states as cited and discussed earlier in this paper.

Clearly it is Boeing’s reputation and future as a viable and thriving company that is on the line with the 787, not that of the FAA. Governmental agencies will always survive any 787 in-service 787 FST disasters, but Boeing could well be mortally wounded, if such circumstances arise and accident reports then cite Boeing design and test culpability just as happened at De Havillands re the Comet in-flight disasters all those many decades ago.

Given the data and background cited and discussed in detail in this paper, I wish to directly address the dedicated and skilled Boeing engineers directly.

Are you comfortable in verifying to the flying public and your fellow composite aerospace engineers that the new generation of commercial aircraft with cf/epoxy fuselages and wings are as safe as you can reasonably make them and that they represent an improvement in safety over all past commercial aircraft as was cited as
a clear Boeing policy by Walt Gillette a few months back? Further, have these data been proven so by your internal developmental tests based upon a performance of a series of full scale fuel fed ruptured or penetrated fuselage tests and also other tests involving opened exits and slides fuselage FST fuel fed fire tests for down wind conditions been conducted by Boeing? Are all doors, exits and slides fully fire test verified in full scale regarding operation in a survivable crash situation?

I am not speaking here of simulations or analyses, but actual full scale fuel fed ruptured or penetrated fuselage FST tests and with similar open exits, open doors and deployed slides similar fuel fed full scale FST tests for such scenarios. Finally, have actual wheels up landing tests been conducted concerning auto ignition risks and subsequent fuselage fires been successfully conducted at Boeing?

This aerospace composites engineer will rely upon your veracity and ethics, but if no engineering published data and detailed answers concerning design or scope of such FST tests are forthcoming in the near future, and certainly prior to final FAA certification from the responsible Boeing 787 structural and test engineers, then other aerospace engineers and myself will be forced to continue to question and cite our serious concerns regarding FST hazards for the cf/epoxy fuselage. In turn, we will be left wondering whether the currently designed 787 series with cf/epoxy fuselage is possibly a bridge too far and too soon for both Boeing and the aerospace composites industry.

In considering your responses to the questions and issues posed by this paper regarding FST risks and issues, I hope that you will be always be guided by the great Boeing heritage and its outstanding safety record over the years, your own core beliefs as dedicated engineers and always, I trust, by asking yourselves, in your internal company discussions and design of such FST full scale tests, whether Bill Allen, Joe Sutter and Chuck Kahler would approve of your opinions and concur with your testing, data results and conclusions, thank you and I look forward to your thoughtful and detailed responses. I know that such is a heavy responsibility, but I also believe in the integrity of aerospace engineers at both Boeing and Airbus. Thank you for your attention and I hope and trust that a wide-ranging but responsible and respectful debate upon these issues will now both possible and encouraged.

Clearly, with the advent of large commercial composite aircraft our aerospace industry is striving to make a major step forward in efficiency and productivity. However, equally clearly, such advances bring serious attendant potential FST risks concerning the epoxies currently being employed as has been detailed in this paper. These risks clearly dictate and demand that close and ongoing design and safety scrutiny be continuously be conducted at all stages and on all components, coupled with a wide ranging, well designed and objective series of full scale ruptured, penetrated or open exit fuel fed full scale fuselage FST tests being performed to fully satisfy ourselves as engineers, not just the certifying authorities, that we have addressed and tested for as wide range of survivable crash scenarios as is feasible and that both the 787 and A350XWB will thus significantly advance both passenger safety and enhanced passenger survivability in any in-service future events and incidents.
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