SAFETY WITH COMFORT IN THE PASSENGER CABIN

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Today's modern airliner is the outgrowth of many years of design progress where passenger safety has been the cornerstone. From a purely practical viewpoint, the passenger must first have sufficient confidence in flight safety to embark on his first flight although frequently he does this with much trepidation! On the other hand, we are all to some degree, comfort conscious. In fact, a feeling of safety is in itself a very basic form of mental comfort.

It is my intent to review with you several areas where safety and comfort relate to the passenger cabin design of today's aircraft. Each of you is uniquely qualified to assess this safety-comfort relationship. You've all had your body transported mechanically from one place to another! I dare say a surprising varied and certainly fascinating envelope of transportation media would result from a pole of this audience.

The Star Ferry in Hong Kong -- did you ride first or second class -- did you stand -- did you smoke -- were you jostled by a "hard landing"? Trams still form the backbone of Melbourne's public transportation system. The Tokyo subway system and Monorail each have unique characteristics. The lift in your hotel is another form of transportation. The wide variety of human factor considerations in all of these is readily apparent.

Even in your home the interface between safety and comfort has dramatic but practical examples. The bottom surface in a bathtub that also contains a shower, requires some sacrifice in personal comfort if a rough nonskid texture is added to preclude the severe accident slip hazard. Our home ranks high on the hazard/accident scale. My point, of course, is that we all live daily with safety-comfort relationships in our homes, offices, automobiles and various other modes of transportation.

Let's take a look at the passenger cabin of today's modern, wide-body jet airliner. How's this for comfort? (Figure 1) Really first class, isn't it? Even at lower cost to the passenger in the coach section, a high degree of comfort can be achieved. (Figure 2)

Perhaps some quotes from Webster's dictionary are appropriate here to help define our terms.

"Comfort" – let's use the noun, not the verb! Some definitions that seem appropriate are:

- "Contented enjoyment in physical or mental well being."
- "A person or thing that brings aid, support or satisfaction."
- "An appurtenance or condition furnishing mental or physical ease."

And now for "Safety" – the other side of our coin:

- "To protect against failure, breakage or other accident."
- "The quality or state of not presenting risks."
- "The condition of being safe. Freedom from exposure to danger. Exemption from hurt, injury or loss."
Figure 1

FIRST CLASS COMFORT

Figure 2

SPACIOUS INTERIOR
The cabin designer is faced with the challenge to meld these two basic requirements into a viable, producible and saleable product.

I intentionally defined comfort first because you — "my representative passenger" — are highly comfort conscious. You generally pick the most comfortable available seat when you enter a room. You take it for granted that they are all equally safe! Rest assured that in the airplane, the safety requirements are the same regardless of whether you are forward or aft of the class divider.

We can't afford to tradeoff safety, but safety does require acceptance and frequently action by the passenger. As a safety specialist, let me show you a super safe environment. (Figure 3) Far fetched you say? Our astronauts needed -- and got -- just such a design philosophy. But today's passenger resists safety belts and shoulder harnesses in his automobile. He frequently must be coaxed or lectured to "Fasten your seat belt PLEASE" in an airplane.

Perhaps you, the passenger, would prefer this as the ideal comfort environment. (Figure 4) Obviously, this concept drastically overlooks safety.

Of course, the optimum design must rest somewhere between these two extremes. The trick is to separate and understand the important factors involved so that a balanced and viable design results.

A study in 1974 by Jacobson and Martinez, published in Human Factors, provides a well documented insight into the reactions and attitudes of today's traveling public. Two particularly appropriate areas of their study are germane. They determined the rank order of comfort variables (Figure 5) and the rank order of satisfaction variables in air travel. (Figure 6)

It is interesting to note that in the satisfaction variables safety ranks first and comfort is fifth. However, the intervening factors of reliability, time savings and convenience are not the cabin designer's direct responsibility if viewed in the broad context.

**ULTIMATE PASSENGER SAFETY**

Figure 3
Now let us look at the individual comfort variables from the designer's viewpoint.

Temperature

No other mode of passenger travel encounters such wide variations in ambient air conditions during such short periods of time as does air transportation. Today's airliner offers substantial improvement in air freshness and rate of air movement, humidity reduction and uniform temperature gradient.

Ground airconditioning units connected to the airplanes and jetways to airconditioned terminal buildings help to avoid the undesirable environment differential shock experienced with older aircraft and airports. However some challenging areas remain:

- Historically, cabin sidewalls have tended to be cold. Much effort has been expended to assure that the cabin window frames and sidewalls do not chill the passengers' shoulders.

- Individual air outlets, or "gaspers" in more general parlance, continue to be controversial. To a passenger who feels overly warm, although others are comfortable and happy, there is nothing more refreshing than a cool flow of fresh air. But his seat mate may not appreciate it if he is forced to share the air flow. The design, control and location of these devices requires skill. In past years small fans were used; and even in some aircraft today, the air outlets provide only recirculated cabin air rather than serving as a source of fresh air.
• Adequate air circulation is required to assure that the passengers throughout the cabin are afforded acceptable temperatures. It is also extremely important to clear away cigarette and cigar smoke as well as various other odors.

• Excess humidity has been controlled to avoid the visible "fog" associated with earlier air conditioning systems. Getting "rained on" is extremely rare. Today the problem of very low humidity is receiving increased attention. Serious design consideration is currently being given to humidifying the cabin air during long, high altitude flights. Flight crews already are aware of this need.

Seat Comfort

A close second to temperature as a comfort variable is seat comfort.

Passenger seat design and production has become a separate and specialized industry. It is a great challenge to design the seats to include the many desired and necessary features. As you probably know, the seats are generally selected, and usually supplied, by the airline as "Buyer Furnished Equipment". Normally, the airplane manufacturer provides only a comprehensive interface document which clearly defines the seat requirements for his particular airplane.

Some factors which influence passenger seat comfort and safety are:

• Structural requirements
The seat strength must conform to strict FAA and/or other certificating agency requirements. Here, both the seat and airplane manufacturers are constantly striving to improve the seat's ability to not only sustain the required loads but to achieve the safest failure mode when these loads are exceeded.

• Seat cushions
The seat cushion design has received a lot of attention from the Human Factors engineers. Appropriate effort by the seat manufacturers has resulted in variable density foam cushions which more effectively cope with the passengers' weight distribution pattern.

Similarly, we've progressed to the point where inflatable or mechanically variable lumbar support is significantly improving passenger comfort. By the way, we're also having good luck with pilot's seats in this field.

• Seat back design
The relative merits of hard shell versus upholstered seat backs may be debated. Regardless, protrusions, steel tube structure and high sharp-edged food tray support structure should be avoided to delethalize the head strike area. Excellent design improvements in this area can be found in many of today's new seat designs.

Where removable armrests are not required, side mounted food trays in the armrest provide an alternate to the seat back tray mounting. This greatly contributes to delethalizing the seat backs.

Certainly, it is obvious that the greater the passenger seat pitch, the greater are both passenger comfort and safety.
• Armrests
A notable tradeoff problem exists here. As I just stated, the armrest with a built-in food tray is preferable to food trays in the seat back. However, a removable or hinged armrest is a boon to the passenger for lounging or even sleeping when the passenger load factor is low enough to permit it. The ill wind blows good for the tired traveler.

• Break-over seat backs
Although not a direct contributor to the comfort of the normally seated passenger, break-over seat backs are a great help when a stretcher is needed to move an incapacitated passenger. This type of seat back also contributes greatly to reducing the seat storage space in your maintenance facility.

Here are a few representative passenger seats with some of the various features we’ve discussed. (Figures 7, 8, 9, and 10) These also illustrate some specific examples of the following features:

![SINGLE SEAT](image)

Figure 7
FIRST CLASS SEATS – SINGLE AND DOUBLE

Figure 8

Figure 9

CONVERTIBLE SEATS
2 FIRST CLASS/3 COACH
COACH CLASS SEATS
HIGH DENSITY
4 ABREAST

Figure 10

- Controls — Recline and Passenger Service Units
Here’s an area where much good work has been accomplished (Figure 11); perhaps much remains to be done. We’ve all had the seat back that refused to remain upright despite the stern admonition by the flight attendant to “Please return your seat back to the upright position”. The seat controls must be simple to operate, with easily understood labeling and no finger pinching hazards. These, too, are the mark of the thoughtful and safety conscious designer.

- Seat belts and buckles
Now here is a very important safety area. The buckle and its release must be simple, positive and quick. Should its operation be included in the safety briefing and instruction card? Some passengers have been baffled by that mechanical marvel — the buckle. A proper seat belt and buckle leads to the passenger feeling comfortable with his surroundings and also being safely secured in his seat.

- Ash trays
Even the non-smokers may want to stuff the ash trays with chewing gum wrappers and olive pits. But he doesn’t want to snag his clothes or break his fingernails. Should the ash trays be the jewel box or pull-out drawer type? Where should they be located; top, front or side of the armrest? An ash tray that is conducive to use will help keep the cabin looking neater and will lessen the chances of a smoldering cigarette igniting paper trash or a seat cushion.
• Seat leg design
Besides meeting strength and "fail-soft" requirements, the seat legs must not scratch our shoes or rip our clothes! They should be attractive too so that they blend well with the general cabin decor.

The seat legs and the other "stuff" under the seat (multiplex boxes, baggage restraint bars, reclining back mechanisms, etc.) must leave ample space for the passenger seated just aft to put his feet. Sufficient clearances and protection must be provided for the passengers' shins.

• Assist step
A properly designed step, integral with the seat, is an aid to stowage compartment access. Here's a good place for the safety conscious designer to create a truly safe passenger seat. It's certainly undesirable to have the attendant slip, fall (they bruise easily too) and disturb the passengers' comfort. Of course, properly designed overhead stowage compartments that can be reached without an assist step solves all these problems.

• Life vest stowage
The life vest must be easy to reach and retained by fittings that will not interfere with rapid retrieval. Yet the life vest installation must be unobtrusive so that its presence is not a continual reminder to the passenger that there is a change that he might need a safety item. This would only contribute to his apprehension and consequent discomfort.
Speaking of life vests brings to mind the life rafts. Although both are rarely needed, inflatable escape slides can be designed to serve the dual function of an emergency evacuation device and a life raft. It is no longer necessary to select robust male passengers to assist in deploying the heavy, bulky rafts out the door and getting them inflated. Now the raft is automatically deployed, inflated and tethered at each cabin egress as soon as the door is opened by the flight attendant.

**Bouncing and Rolling**

These two annoyance factors have been significantly reduced with the advent of today's jet aircraft. The higher wing loading with swept wing design, use of weather radar, greatly improved autopilot and stability augmentation systems, and generally smoother air at the higher altitudes have enhanced the ride quality of today's transport. However, clear air turbulence, wake turbulence and sharp edge gusts plus climb and descent through normal turbulence do present problems affecting the cabin interior design.

- **Overhead stowage**
  For many years passengers were admonished (and irritated) against placing heavy articles in the overhead rack -- and with good reason. Today's cabin interior designs have taken a forward step with the use of enclosed overhead stowage compartments with doors and latches that are resistant to inadvertent opening. (Figures 12 and 13)
• Delethalization design
Considerable attention is being given to the elimination of sharp corners and edges as well as protuberences that present a hazard to passengers and cabin crew alike. Careful attention must be paid to carpet edging, level continuous floors and flush door thresholds. Fixtures and containers in the toilets should be recessed or flush to avoid injury. Door and latch designs should be simple, sturdy and as foolproof as possible. Convenient and properly located handles must be provided to permit the passenger to steady himself during turbulence. (Figure 14 and 15)

These features are also necessary to prevent injury during the maneuvers required for collision avoidance.

Noise

We are all sensitive to both interior and exterior noise. In today's airplane, the overall sound level has been reduced to where the annoying Speech Interference Level (SIL) noise may come from the snoring of the passenger in the seat next to you. In general, it's possible to converse with your seat mate in a normal tone of voice -- you may even have to lower it if you want privacy. Many of our interior noise complaints today are coming from insufficiently muffled mechanical noises like landing gear operation, motors, hydraulic pumps, noisy valves and plumbing. Even the noise of the air flowing out of the air conditioning ducts and the noise caused by possible air leakage through cabin door seals is now noticeable.
DELETHALIZED AMENITIES

Figure 14

TOILET

Figure 15
Cabin vibration, formerly a problem in reciprocating engine powered transports, has been effectively eliminated as a passenger comfort factor.

An interface between safety and comfort is in the understandability of the Public Address System. Here the cabin noise level and the system fidelity must be adequate. (So should the content of the announcements!)

Lighting

It is obvious that the normal cabin lighting plays an important part in supporting a comfortable and safe environment.

However, emergency lights also must provide adequate illumination to permit passengers to find an emergency exit from their seated location under the most adverse conditions of visibility. Lights and signs must provide clear, unmistakable directions to locate suitable exits in the event of an emergency. The possibility of darkness and smoke in the cabin must be considered in establishing the level of illumination and the visibility of signs. Satisfactory operation of emergency lights and visibility of signs is required under conditions of fuselage separation. Individual battery powered lights incorporating their own charger and actuation system have been developed. The contrast between sign lettering and their background are prime safety considerations. With the advent of world wide travel, the development of universal pictographs is essential to overcoming the language problems. Significant progress has been achieved in this area but there is still a need for continued improvement.

Presence of Smoke and Pressure Changes

Today's Environmental Control System (ECS) design has indeed reached a level of excellence. As I mentioned before, adequate air circulation keeps the cabin quite clear of smoke. Precise control of the cabin altitude rate-of-change precludes the abrupt cabin pressure bumps in yesteryears transports.

Work Space

Although least rated in the comfort variables, work space for the passenger is closely allied to seat comfort. The most obvious factors are:

- Seat pitch
- Seat width
- Armrest width and height
- Tray or table design

We have touched on the comfort variables related to the Jacobson and Martinez study. Now let's look at some specific design areas.

General Cabin Design

Spacious cabins, which are provided by the widebody jet aircraft, permit a lot of flexibility for cabin seating arrangements and the placement of various passenger amenity units throughout the
cabin. These spacious cabins give the designer more freedom to specify seat widths, seat pitch and aisle width. These contribute to the ability of the passenger to move about in the cabin. A walk up and down an aisle does break the monotony of a long flight. These large aircraft also permit the designer to divide the passenger cabin into separate compartments. This avoids the long, tube-like appearance of some of the older, long fuselage, narrow body jet aircraft. This ability to divide the cabin also avoids the visual disaster of having a sea of people visible within a given passenger cabin area.

The new widebody jet aircraft all incorporate wider and higher passenger loading doors. These doors permit far easier access in both boarding and deplaning operations. These door also eliminate one of the chronic problems on earlier aircraft; that of the ever present head knocker or low overhead encountered when passing through the door.

One of the most significant advantages provided by the widebodied jet aircraft, and by some of the retrofit kits for earlier narrow body aircraft, is the incorporation of the previously mentioned enclosed overhead and carry-on baggage stowage compartments that are available to the passengers. (Figure 16) These compartments permit the out-of-the-way stowage of copious quantities of precious, hand-carried goods that are brought aboard by passengers in nearly every country. These compartments give the passenger the privilege of private stowage of and ready access to items that he may wish to carry aboard and not trust to normal baggage handling. Of course, getting the hand-carried baggage out from under the seats now provides unhindered room for the passengers' feet.
Coat stowages (Figure 17) are now located at better distributed locations throughout the passenger cabin. This provides a certain measure of convenience to the flight attendants in their initial acceptance of and access to the passengers' coats throughout the cabin.

Galley Design

There has been a trend toward installation of galley facilities at either remote locations in the passenger cabin or by removal of these facilities from the passenger cabin entirely and locating them in the lower (cargo) level of some of the larger aircraft. (Figure 18) The latter system also avoids a lot of the typical galley clatter and odor problems with which we are all familiar. In the case of cabin level facilities, on many occasions they are installed at either end of the passenger cabin or at points representing the line of demarkation between coach and first class service. (Figures 19, 20, 21 and 22)

The location of galley units remote from the main concentrations of seated passengers, in addition to improving their local environment by lowering the confusion level, noise and odor, also improves the emergency evacuation conditions. When galley areas must be used as evacuation paths, the use of secondary or backup latching devices measurably reduces the blockage potential created by spilled galley contents and equipment.

The floor covering in the galley areas must serve a dual purpose. Of course, it should look attractive and fit in with the overall decor. The floor covering must also be a non-skid surface when wet from spilled liquids as well as when dry. The footing for the flight attendants must be secure so as not to create a hazard while they are performing their duties.
One aspect of the galley design is the use of food, beverage and waste carts or trolleys. Originally, meal service to the passengers was provided by the flight attendants scurrying up and down the aisle carrying food and beverages and later retrieving the soiled tableware. For obvious reasons, this service was temporarily suspended whenever turbulence was encountered. Then, when the wide-bodied jet aircraft with two cabin aisles entered service, the use of carts became popular in an effort to cope with serving the increased number of passengers in the available flight time. This also allowed for more personalized service which enhanced the luxury/comfort aspects of air travel.

But the ugly specter of 200 pound plus carts bouncing around in the aisles during turbulence raised its head. We have researched various means of restraining the carts to the floor continuously along the aisle; sort of a shoe sliding in a long slot. We can even design containers suspended from a track in the cabin ceiling over each aisle so that they could be moved along the length of the cabin. But so far these schemes have been deemed to be impractical from weight, maintainability and flexibility standpoints.

For those operators who choose to offer meal service from carts in the aisles, the carts may be equipped with tethers to secure the cart to the adjacent passenger seats or retractable tie-down fittings are installed in the floor at intervals along the cabin aisles. In the latter case, the existing mechanism on the underside of the cart which secures it to the various takeoff and landing tie-down locations is also used to secure it in the aisles. Some regulatory agencies require that the carts be secured at all times in flight except when actually being moved from point to point.

Other operators have chosen a compromise procedure. The carts are used essentially as a conveyance for the commissary crew to remove used meal service equipment from the cabin and to restock...
the galleys or service centers. In flight, the attendants move the carts and secure them at other locations such as doorways and satellite service centers. They then revert to the original aisle scurrying technique although they don't have so far to go along the aisle.

All of this is meant only to illustrate that safety is always of prime importance even to the sacrifice of some level of luxury and comfort.

Flight Attendants Stations

The design of the flight attendant station is one of the most critical single items in the passenger cabin. Comfortable surroundings for the flight attendant leads to more efficient work and pleasant service to the passenger. The safety aspects of the flight attendant station are of utmost importance since survival of the flight attendant is a key element in the protection and safety of the passengers in emergency conditions.

The flight attendant seats are free standing and attached to primary structure. (Figure 23) For decor purposes, these seats may look as though they are integral with partitions and bulkheads but in fact they draw no support from these non-structural elements. (Figures 24, 25 and 26) We have had at least one severe but survivable crash of a widebodied transport wherein we can take some comfort from the fact that all of the flight attendants seats remained intact.
FLIGHT ATTENDANT STATION
MAIN ENTRANCE DOOR

Figure 24

FLIGHT ATTENDANT STATION
MID CABIN CROSS AISLE

Figure 25
The use of an integrated lap belt and shoulder harness is strongly recommended. The need for the shoulder harness on forward facing attendants seats is obvious. However, even on aft facing seats the shoulder harness will greatly contribute to the attendants' safety during the subsequent random motions following initial impact. I think we all recognize that aft facing seats are preferable but sometimes this cannot be achieved because of other considerations in the cabin design. In these cases, utmost effort is expended to ensure the attendants' safety and survival.

Emergency equipment, such as fire extinguishers and portable oxygen, should be stowed in or immediately adjacent to the flight attendants stations. Stowage for the attendants' life vests and spare life vests are also located here. The intent is to install these items where they are readily available to the flight attendants and yet are unobtrusive to the passenger. In aircraft intended for over-water operation, in addition to life vests, the bottom and back cushions on the flight attendants seat should be bouyant. The cushions should be held in place by Velcro tape or snaps so as to be easily removable. The availability of anything that floats could literally mean the difference between life and death.

The flight attendants' interphone handset, the passenger address microphone and the controls for the cabin lighting, audio and visual entertainment should all be installed so that they can be reached and operated by the attendant while in the seat. (Figure 27) There is no reason why the flight attendant should not be afforded the safety of being secured in the seat during taxi, take-off and landing, and turbulence while still performing some of the required duties of the job.
Crashworthiness

One thing we always are reluctant to admit is, simply, that at some point in time there will be a landing of an aircraft in a possibly planned but abnormal manner. This then brings up factors that must be considered in achieving a maximum passenger survival rate in any landing from wheels up on a foamed runway to a survivable type of crash. Passengers are not directly concerned with the mechanics of a crash landing. But they expect that the basic airplane design will be sound with reliable and functional systems and that the aircraft will be capable of withstanding a variety of mishaps while still maintaining normal operation. A number of advances have been made in various technologies that have stemmed from a more general realization of the design concepts involved with crashworthiness.

- There is a growing trend toward installation of food trays in the passenger seat arms in lieu of the conventional seat back tray that has been in use for so many years. The attractive feature related to the seat arm tray is simply that another hard surface is removed from that area within which a passenger's head may swing and strike when subjected to decelerations typical of crash landings.

- Upholstered seat backs are gaining in popularity over the hard or shell back seats. This increased popularity is due to the overall lower maintenance coupled with the improvement in luxurious appearance afforded by the upholstered seat back. Of course, there must be adequate padding over the basic seat structure beneath the upholstered seat back to preclude head injury.

- For many years we've been hearing about the advantages of rear facing seats as a contributing factor towards passenger survivability. There has been some research along
these lines, a good bit by the automobile manufacturers. There have been some military transport aircraft that were equipped with rear facing seats but there is little, if any, data on the true effectiveness of this feature during actual crash conditions. We have seen that the fuselage or fuselage segments seldom come to rest such that aft facing seats would have afforded the protection expected of them.

Aft facing flight attendants seats have afforded good survivability but please recognize that many of these seats are equipped with shoulder harnesses as well as lap belts. To the average airline passenger, shoulder harnesses, whether used with aft or forward facing seats, probably would require too much of a comfort sacrifice; he would not feel comfortable when literally strapped into his seat. An all rear facing seat configuration would not only be unconventional but we know that it would create adverse passenger reaction.

- The regulatory agencies require the delethalization of lounge tables, class dividers, door frames, and other hard objects within the head strike envelope of the passenger in a deceleration environment. This envelope is described as parallel to the aircraft centerline and including an angle of 15° on either side of center to take care of yaw attitudes during exposure to the crash environment. The addition of padding or smoothing of angular surfaces adjacent to the seated passenger can actually improve the feeling of spaciousness and comfort and the aesthetics of the interior installation.

- The use of "solid state" or chemical oxygen generators in place of a gaseous oxygen supply for emergency use after an aircraft decompression is becoming more widespread. In an environment where fire actually exists, gaseous oxygen can greatly affect the propagation of the flames. "Solid state" oxygen, actually generated within the individual cannisters, supply only low pressure oxygen to the passenger masks. They do not provide enough oxygen to significantly support combustion even during the oxygen generation process.

- Additional attention has been focused upon some of the human elements involved with behavioral inaction in spite of the presence of an environment adverse to survival. Many instances have been documented whereby passengers, though surviving the crash impact, have actually failed to react in time to escape from a burning aircraft. Cabin crew training, cabin layout and recognition of less-than-satisfactory evacuation conditions are all important to overcoming this basic human reaction. Wide aisles, well defined exits, simple emergency instructions and improved safety measures for the cabin crew (insuring their high survival rates) all contribute to lessening the effect of behavioral inaction.

- A lot of attention has been given to the flame, smoke and toxic product characteristics of burning cabin trim materials and fabrics. However, regulatory documentation can not control the fatal inhalation of just one lung-full of hot air from a fuel driven fire. We must also recognize that it is not feasible to have a complete aircraft that will be devoid of all products of combustion, smoke or toxic gases which can adversely affect passenger survival. Comfort standards required by commercial passengers will not permit acceptance of this type of aircraft interior treatment. New synthetic fibers, such as Kynol, PBI and Nomex, have been developed that exhibit many favorable flame and smoke characteristics. Phenolics for laminates and thermo setting polycarbonate for injection molded plastic parts are typical of improved interior materials. However, these materials are all organic in composition and will produce varying quantities of toxic gases when burned. New products must be developed that will advance the state-of-the-art in this particular area with special attention to their use in the overhead or high heat areas.
I’d be very remiss if I didn’t give you a peek at what the inventive interior designer has just done and will soon do -- safety with extra comfort! (Figure 28 thru 33)
22 PLACE FIRST CLASS DINING ROOM

Figure 32

9 PLACE SLEEPING BERTH

Figure 33
We've come a long way from the cabin of the Ford Tri-motor (Figure 34) and we have far yet to go. The field of aviation safety has many facets and cabin design plays one very important part. With the help of seminars like this, continued progress in safety with comfort in the passenger cabin will be achieved.