Safety Devices for Cessna-152

Glide Assisting Device
Energy Transfer Device

IDEAS
CREATING ANSWERS

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Ted Renteria   Implementation (Group)
Cessna - 152
“On every flight
there is only so much time you can spend
in the air...”
ABOUT ME

1 - Diversity
2 - Change
3 - Challenge
4 - Adventure
What are accidents and why do they happen?

Accidents are defined as “unexpected events that cause property damage and/or injuries to people”. Prior to any accident happening, however there is an emergency situation at hand. Time available to deal with the emergency may vary. Pilots brain power can decrease by 60% during an emergency, due to stress. Processing of information is slow. Natural behavior can take over learned behavior. Source of emergency may be unknown. The less time is available to solve the problem, the more stressed the pilot becomes, which could worsen the situation.

Also sometimes problems can be of a nature that is not obvious, so the pilot may not even be aware that there is a potential emergency situation at hand. When such a scenario occurs, the pilot is unable to take precautionary measures and is unable to react appropriately at that moment when things get out of control.
HYPOTHESIS

1. If a device can prolong the time period that a pilot can spend in the air, he/she will have a better chance of solving the problem and land safely.

2. If a device can stabilize the aircraft’s nose gear on landing, by reducing the severity of impact, thus preventing immediate structural failure, this can potentially save many lives.
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References
1. Introduction

1.1 Why is it Necessary to Increase Safety in General Aviation Aircrafts? Is Flying Dangerous?

Flying is often compared with driving when discussing safety. A general misconception is that flying is safer than driving. While this is true for big airliners, this is not the case with general aviation. Big Airliners have a crash rate of 0.34 per million flight hours, while general aviation is 50 times more dangerous.

General Aviation Aircrafts such as Cessnas are 50 times more dangerous than big airliners and 20 times more dangerous than cars.

Philip Greenspun in his article: “General Aviation Safety”, made very detailed comparisons between General Aviation and driving in terms of safety:

“There are 16 fatal accidents per million hours of general aviation. It is fairly safe to assume that when a plane crashes and someone dies, everyone on board dies. By contrast, the death rate for automobile driving is roughly 1.7 deaths per 100 million vehicle-miles. Car crashes don’t always kill everyone in the car so let’s use this statistic as provided, which is for an individual traveling in a car rather than for the entire car. So considering that the average airplane accomplishes a ground speed of at least 100 miles per hour, those million hours of flight push the occupants of the plane over more than 100 million miles of terrain. Comparing 16 fatal accidents to the 1.7 rate for driving, we find that flying is about 10 times as dangerous per mile of travel. And since most accidents happen on takeoff or landing, a modern light airplane traveling a longish distance might be comparable in safety to a car.

We can also look at safety per hour. If the average speed of car travel is 50 miles per hour, those 1.7 deaths occur in 2 million hours of driving. This makes general aviation, with 16 deaths per 1 million hours, roughly 20 times as dangerous per hour than driving.”

Even though Cessna’s are well known to exhibit very good stability during flight, they are not made safe in case something would go wrong and the pilot is forced to crash land.

However flying is different than driving. Up in the air a totally different environment exists, and vehicles that operate in such an environment must meet many factors, that may not be necessary to be considered in vehicles operating on the ground. Any new safety device must be designed to fit this unique environment.
1.2 Why Cessna-152?

1 - Cessna-152 is one of the most popular small airplanes ever produced and is used in thousands of flight schools all over the US and beyond to train pilots. The main reasons why they are so popular is because they are more easy to fly and are generally more forgiving to mistakes.

C-152 is one of the most popular small airplanes ever produced!

2 - Cessna-152 is very popular among private & recreational pilots too. The FAA states that currently there are 597,109 pilots in the US and 91,343 Flight Instructors. Cessna-152 is part of the General Aviation sector, which comprises 80% of all aircraft in the US. This sector compared to the military and commercial airline sectors, is the least safe.

80% of all aircraft in the US are General Aviation types, but they are also the least safe of all!

3 - Cessna-152 is the aircraft in which I learned to fly like many other student-pilots. During my time at the flight school, I had a personal experience with a potential dangerous aircraft failure. I discovered later, that it is a quite common occurrence, which inspired me to take a closer look at the problem. The airplane in which I and other student pilots were flying, had developed cracks around the nose gear, which could have lead to nose gear collapse on landing and a potential fatal accident. The cracks were discovered by a routine maintenance inspection, however I was told that often damage of this nature would go unnoticed. Also often pilots and instructors were telling stories of friends and even family members, who were involved in small aircraft accidents and died, because of fuel shortage in the air or a problem with the engine, that lead to landing on unsuitable terrain and death.

Personal Experience guided me
2. Goal of Devices

A Summary

To prevent injuries and/or safe the life of the pilot through:

Protection

First line of Defence

Active Safety
Active safety features are those that prevent or reduce the likelihood of accidents from happening.

C-152

Aircraft Structure
Activated by: Human

Cruise
New Device should:
Increase Time available for pilot prior to impact

Landing
New Device should:
Increase Time available during impact

Second line of Defence

Passive Safety
Passive safety features are those that minimize the probability of injury if an accident does occur.

Target User

Activated by: Machine

Student Pilot

Private Pilot (YRB + JRB)

Flight Instructor
Accident Sequence Chart that leads to Injury and/or Death

Design Focus Area:

<table>
<thead>
<tr>
<th>Cruise</th>
<th>First Line of Defence</th>
<th>Prior to Impact</th>
<th>Problem in Air</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landing</td>
<td>Second Line of Defence</td>
<td>On Impact</td>
<td>Airplane Collision</td>
<td>2</td>
</tr>
</tbody>
</table>

Severity of Accident Range, which the new device is designed for:

- Minor Injuries
- Serious Injuries
- Fatal Injuries

Slight Damage to Aircraft

Substantial Damage to Aircraft

Destroyed Aircraft
Cruise
New Device should:
Increase Time available for pilot prior to impact

Landing
New Device should:
Increase Time available for pilot during impact

Aircraft Structure

Name of Device
Glide Assisting Device

Name of Device
Energy Transfer Device

How will the Devices Increase SAFETY?

1 - Retrofit Glide Assisting Device
The Aircraft will be made more Forgiving through creation of Safety Nets that:
Extend glide range through mechanically deploying a device that will increase the surface area of the wings and reduce overall wing loading, transforming the aircraft into a better glider. See next page for simple illustration of what general scenario the device aims to improve on.

2 - Retrofit Energy Transfer Device
The Aircraft will be made more Forgiving through creation of Safety Nets that:
Prevent or extend time for structural failure to occur on landing by reducing the force of impact and allowing momentum to change over a longer period of time.
To achieve this the new device will aid in energy absorption and energy transfer as well as exhibit deformation control ability allowing the nose gear to react more favorably to impacts and to sudden changes encountered on the runway surface, dissipating some of the energy, to prevent it from passing directly to the power plant and then to the pilot.

Crash events are usually non-linear, however research has indicated some predictable failure patterns of nose gear collapse:
1. Rearwards rotational (most common)
2. Upwards (vertical)
The new device will deal with those two scenarios. See next page for simple illustration of what general scenario the device aims to improve on.
1. Pilots will have more time to inform the Tower of problems, so that Air Traffic Control can send timely warning to other aircrafts in the area, avoiding midair collisions.

2. Pilots will have more time to solve the problem if it can be fixed.

3. Pilots will have more time to find suitable crash terrain.

Crucial Point is moment of TOUCHDOWN
The device should be automatically activated at this moment to prevent the dangerous chain events from occurring or minimize the severity of the impact by absorbing and transferring impact energy.
3. The Market

3.1 Who is the Target User?
The target users are pilots that use the aircraft C-152 or the very similar C-172. Common users of such aircrafts are:

![Image of pilot categories: Student Pilots, Private Pilots (VFR + IFR), Flight Instructors]

The FAA pilot statistics shows there are now 597,109 pilots in the USA. The youngest group is the student pilot category where the average age is 34.4 years old.

3.2 Which User Segment is Most Likely to Get Involved in an Accident?

Pilots and accident proneness - Age difference

Inattentiveness is more common in younger pilots, while flawed decision making is more prevalent in older pilots states the. Overall, about one-fourth of the pilot errors is attributable to inattentiveness, and about a fifth each to flawed decisions, mishandled aircraft and mishandled runway conditions. The Johns Hopkins team concluded, "neither crash circumstances nor the prevalence and patterns of pilot errors appeared to change significantly as pilots aged from the 40s to 50s and early 60s."

Pilots and accident proneness - Level of experience

The Johns Hopkins research team further examined the relationship between age and safety in "Age, Flight Experience and Risk of Crash Involvement" an article published in the American Journal of Epidemiology. The authors found that "Total flight experience showed a significant protective effect against the risk of crash involvement. With adjustment for age, pilots who had 5,000 to 9,999 hours of total flight time had a 57 percent lower risk of a crash than their less-experienced counterparts. . . . The protective effect of flight experience leveled off after total flight time reached 10,000 hours."
3.3 The Average Accident Pilot Profile

The pilot involved in the average accident is likely to have the following profile:

- The pilot is likely to be between 35-39 years of age.
- The pilot is likely to have between 100 and 500 hours flying experience.
- The pilot is likely to be on a VFR personal flight.

- 60 hours after receiving Private Pilot License;
- 50 to 100 hours after receiving Instrument Rating.

Some reasons that might account for these risk times are:

- At the completion of a training program, students have a high level of skill and confidence, but have very little experience.
- Exposure to risk increases rapidly following training, as pilots are no longer in the protective cocoon of the training program where risks are monitored and controlled.
3.4 Most Common Errors Made by Pilots

Below is a graph illustrating the most common errors made by pilots. Skill-based errors are the most common, which according to the average accident pilot profile on the previous page, indicates that the pilots in this category are mostly students. If the pilot lacks skill there is very little he can do to improve his situation when faced with an emergency, where fast and accurate decisions and actions are required.

The next fatal category are decision errors. When a pilot is faced with an emergency situation he/she has to make decisions. However the source of emergency may be unknown. Stress can be high and time is often limited to find solutions to solve the problem at hand...
The five most frequent decision errors made by pilots are as follows:

- Fuel Management
- Planning/Decision-making on the ground
- Unsuitable Terrain Selection
- In-flight planning
- Go Around

The above points have been confirmed by data gathered from published reports as well as has been confirmed by personal interviews with several experienced pilots.

Every accident is a result of a sequence of errors and a unique combination of internal and external factors. Till today investigators are constantly dealing with newly emerging types of errors due to unique circumstances. Much research of crash sites has been carried out to determine the causes but mistakes are still unpredictable and unpreventable.
Even though pilot error is one of the major causes of aircraft accidents, it is not the sole cause. Let's examine below what other common factors may contribute to an accident to add further to the complexity.

So we can summarize how pilots may get injured or die in three major categories. If any or a combination of the following three categories fail or combine in an unfavorable way an accident results:

However, no matter what the reasons are for an accident to occur in the first place, be it pilot error, mechanical failure or another reason, it is usually the Aircraft that hits the ground or another obstacle first. Only after this happens, the shockwave of the impact reaches the pilot and causes injuries.
3.5 Environment, Aircraft, Human and Accident Chain Events

Below is a diagram summarizing the behavior of all three elements and the role they play in an emergency situation or accident. When one element fails, often a chain event follows which causes other elements to be affected too.

**E** - Environment
**A** - Airplane Structure & Exterior
**C** - Cockpit & Objects surrounding Human
**H** - Human

Direction of Danger flow or chain reaction of damage
Can be an independent start of danger unrelated to previous level

Points to Remember:
Environment in itself cannot be changed. However the way an Airplane acts in an environment may be changed or improved.

The Airplane Structure and Exterior is the first that normally faces the dangers of the environment and is the first that may either provide initial protection that will better protect all that lays in its interior or may fail quickly causing a deadly chain reaction.

The Airplane Structure and Exterior may also in itself fail without the intervention of the environment again causing a dangerous chain reaction to occur affecting the final element of this system - the Human.
3.6 Benefits of Protection

Through better protection pilots can have a better chance for survival even when the skills of the pilot are not optimal or when he encounters an emergency situation due to decision errors or factors beyond his control, such as a mechanical failure. Protective devices can prevent deadly chain events to occur. And if the protective devices manage to extent the time that a pilot has to deal with the emergency, he will have a better chance to handle it more optimally.

To further clarify what I mentioned above we must briefly make a distinction between the inherent differences between man and machine in terms of performance of different tasks. This will also help us understand when it is better to allocate a task to a machine and when to man. For this the advantages and limitations of both must be taken into consideration.

<table>
<thead>
<tr>
<th>Property</th>
<th>Man</th>
<th>Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Overload:</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>1. Gradual</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>2. Sudden</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Reasoning:</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>1. Deductive</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>2. Inductive</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Speed</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Power</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Consistency</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Complex activity</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Short-term memory</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Computation</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Error Correction</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Intelligence</td>
<td>✓</td>
<td>✗</td>
</tr>
</tbody>
</table>

It is also important to consider under what circumstances a device will be used, that may require the involvement of more than one factor, which can add to the complexity. For example a simple task may become difficult for man if he is under a lot of stress. All this is important to be considered when designing a new device.
3.7 Target User and Income.

How Much does it Cost to Own or Fly an Aircraft?

Now that we have a better idea of who our User is, there is still an important question to be answered, that could affect the way the new devices are designed or what price is within the acceptable range. We must remember that pilots are not the only stakeholders. Others are:

- Cessna Company
- Insurance Companies
- Flight Schools
- FAA
- Maintenance Facilities
- and of course Private Buyers among which are the pilots.

For all those mentioned above, cost is a consideration. Aircraft companies want to produce aircrafts & safety devices with as little capital as possible. Also the buyer takes cost into consideration when buying an aircraft.

However as we will see in the following pages, a person has to have a substantial amount of money to own and operate an aircraft. Even just to learn to fly is a huge investment, which the average person cannot afford.

To the pilot as well as to most other stakeholders, SAFETY is also of major importance as well as increasing sales in future through added value. So when we design safety devices for a market segment that is considered to have above average income (note the median income in the US is around $25,000), this will also affect the way the products are designed.

Philip Greenspan said:
“Dying in a plane crash of any kind is one of the hazards of wealth”.
The aircraft Cessna-152 is considered one of the least expensive to own and operate. In today's market if you have about $50,000 you will be able to buy an old version Cessna-152 and even a used Cessna-172. Some Cessna's, such as a 2002 Cessna-172 can cost $148,000. Or a 2000 Cessna-172 Skyhawk costs almost $100,000. A 2000 Cessna-172 Skyhawk costs $170,000. A 2004 Cessna T182T costs $250,000.

The direct operating cost might be anything from $25/hour to $500/hour. The cost of the first annual inspection might be $500 or $5,000 or more.
Below is an estimated cost of what it takes to become a Private Pilot or instrument Pilot of a Cessn-152. Those numbers are just estimation and usually it takes twice as much or more to actually get the license. The data below is taken from the school in Oakland, in which I learned to fly. It was the cheapest school in the area. There I was told that 60 hours of training are the minimum required by the FAA. However it takes much longer to actually learn to fly.

<table>
<thead>
<tr>
<th>Estimated Cost of Becoming a Pilot of a Cessna-152 / 172 / Piper</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Private Pilot</strong></td>
</tr>
<tr>
<td>40 Hours flight w/ instructor</td>
</tr>
<tr>
<td>10 Hours solo practice</td>
</tr>
<tr>
<td>20 Hours ground instruction</td>
</tr>
<tr>
<td>Medical examination</td>
</tr>
<tr>
<td>Written examination</td>
</tr>
<tr>
<td>Books &amp; Supplies</td>
</tr>
<tr>
<td>Flight test</td>
</tr>
<tr>
<td><strong>Total (minimum)</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Instrument Pilot</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Hours flight w/ instructor</td>
</tr>
<tr>
<td>20 Hours w/instructor</td>
</tr>
<tr>
<td>40 Hours ground instruction</td>
</tr>
<tr>
<td>Written examination</td>
</tr>
<tr>
<td>Books &amp; supplies</td>
</tr>
<tr>
<td>Flight test</td>
</tr>
<tr>
<td><strong>Total (minimum)</strong></td>
</tr>
</tbody>
</table>
3.8 What the Target User Needs and Wants

The result of a questionnaire that I did was as follows with the highest scores shown below. The questionnaire was given to student pilots, flight instructors and a crash site investigator.

<table>
<thead>
<tr>
<th>%&lt;85</th>
<th>Users Need</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;100</td>
<td>To have a device that would will increase safety, but allow the pilot to remain inside the airplane until landing</td>
</tr>
<tr>
<td></td>
<td>Have a device that can make landing on a less than optimal terrain safer</td>
</tr>
<tr>
<td></td>
<td>A device that will not interfere with regular flight procedures.</td>
</tr>
<tr>
<td></td>
<td>A device that will prevent the airplane from overturning</td>
</tr>
<tr>
<td></td>
<td>A device that will make the nose gear safer</td>
</tr>
<tr>
<td></td>
<td>A device that will allow the pilot to remain in control of the aircraft until landing.</td>
</tr>
<tr>
<td></td>
<td>A device that can help the pilot to gain more time during cruise to solve problem before crashing</td>
</tr>
<tr>
<td></td>
<td>A device that will prevent the propeller striking the ground on landing</td>
</tr>
<tr>
<td></td>
<td>A device that will prevent the engine striking the ground on landing</td>
</tr>
<tr>
<td></td>
<td>A device that will ultimately reduce the risk injuries that pilots are exposed to during a crash</td>
</tr>
<tr>
<td></td>
<td>A device that can be retrofitted, added and removed at will.</td>
</tr>
<tr>
<td></td>
<td>A device that will improve the performance of the aircraft.</td>
</tr>
<tr>
<td></td>
<td>A device that will help the aircraft from spinning out of control on landing.</td>
</tr>
<tr>
<td></td>
<td>A device that is easy to use.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Users don’t need at all</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A device that improves safety on the landing gear, firewall or wing struts as these are considered the strongest structural elements in the aircraft.</td>
</tr>
<tr>
<td></td>
<td>A safety device that will require rearranging major structural components or redesigning the whole airplane</td>
</tr>
</tbody>
</table>
3.9 What Safety Devices are Currently Available for GA Aircrafts?

How safe an airplane is depends mainly on:

- The Environment
  - The Forces
- The Materials
- The Structure
- The User

We discussed the user already. In the next chapter, we will discuss structures, forces, materials and the environment in more detail. In this section we will examine what safety devices are available for General Aviation Aircrafts. Below are the three main sectors of aviation.

- Military Aviation
- Commercial Airline
- General Aviation

80% of all aircraft in the US

Least Safe compared to military or commercial airliners

Cessna belongs in this sector
Aircrafts belonging to each of the sectors have very different performance and safety requirements because they target very different users, that will operate the aircrafts in quite different environments for different purposes.
This is why for example military aircrafts are very advanced in technology and safety, while for instance General Aviation Aircrafts are much less safe, to reduce weight and cost, but pay more attention to styling.
Compromises in design always have to be made. However in some general aviation aircrafts, such as the C-152 and also C-172 the compromises for safety made are too high. Besides that the style is not too appealing either when comparing them to other general aviation aircrafts.
Below is a quick chart, comparing some aircrafts.
High Cost
Complex Aircraft

$485 million

Military Aviation : VH-71 Kestrel

$317.2 - 337.5 million

Commercial Aviation : Airbus

$5.9 million

Military Aviation : Black Hawk

$300,000 - 500,000

General Aviation : C-152/172

$35,000 - 75,000

General Aviation : Cirrus

Low Cost
Simple Aircraft
General Aviation

Cirrus
Advantage: High Safety
Disadvantage: Complex to use + Expensive

Cessna-152
Advantage: Simple to use + Cheap
Disadvantage: Low Safety

New Design Solution
Compromise between safety, simplicity and cost must be made

Most advanced current safety devices in GA Aircrafts:

- Airframe Parachute System
- Inclined Firewall
- Airbag Seatbelts
- Roll Cage to absorb energy
- Terrain Awareness System
- Side positioned control yokes
- Redundancy systems
- Energy Absorbing Seats

There are very few safety devices for GA Aircrafts currently on the market.

Most of the safety devices available, require major structural changes to be made inside the airplane.

Most require permanent changes to be made to the airplane.

For more info and analysis see the Research Binder

However simple safety retrofit devices can solve many problems at lower cost
Materials used in Aviation

In Military & Commercial Sector
- Aluminium Alloys
- Titanium Alloys
- Nickel-Base Superalloys
- Heavy-duty ballistic materials
- Carbon Fiber
- Kevlar
- Speciality Steels
- Metal Matrix Composites
- General Plastics
- Temper (Memory) Foams
- Leather

Most Popular

In General Aviation Sector
- Fiberglass & Fiberglass
- Speciality Steels
- Reinforced Polyester
- Aluminium
- General Foams
- General Fabrics
- General Plastics
- Carbon Fiber
- Rubbers
- Wood
- Leather

Some Future Potentials
- Ap Nano-Spheres
- Intelligent Materials
- Shape Memory Alloys
- T7 Webbing
- Aluminium Foam
- EIS W50 Energy Foam
- Super tough HDPE
- High performance Elastomers
4. Structures, Shapes and Behavior
From Nature to Man-Made Devices

4.1 Structures and their Behavior during Flight

Many man-made structures today have their origins in nature. Structures of various forms behave differently in the air. It is very important to understand this for this project, that deals with designing safety devices for a flying vehicle - the aircraft. So what are the basic forces affecting an aircraft during flight?
What makes an aircraft fly are the WINGS. The wings are a very important part of any aircraft.

How well an airplane glides depends mainly on:

- Aerodynamics
- Weight & Balance

Different wing cross-sections named airfoils, exist. Through their form they each affect the aircraft differently. Some make it fly faster, some maneuver better, some assist in gliding.... We will also see after that, that also the general wing form (plan face) and also the wing tip devices (not only the shape of the airfoil), have an influence on how the airplane behaves in the air.
Even though there are many airfoil shapes, they all function according to Bernoulli's principle:

**Bernoulli's principle:**
As the velocity of a fluid increases, the pressure exerted by that fluid decreases. Bernoulli's principle thus says that a rise (fall) in pressure in a flowing fluid must always be accompanied by a decrease (increase) in the speed, and conversely, if an increase (decrease) in the speed of the fluid results in a decrease (increase) in the pressure.

However to every rule there are exceptions, or designs that somehow do not fit into the mainstream, but exhibit better performance nevertheless.

**Against Bernoulli's principle:**
This airfoil was created and patented by Richard Kline. It is so unconventional that it drives aerodynamics experts crazy. It seems to violate one of the major laws of flight: the Bernoulli principle. Most wings are round on top, flat on the bottom, so air plows over the top. This means the air is less dense on top and more dense on the bottom. As a result there is greater pressure on the bottom, which provides lift. This wing, however, is flat on top and notched — partially hollowed out — on the bottom. Because it has more area on its underside, its "lift" should propel it toward the ground; it should sink like a rock, but it doesn't. The hollowed part causes pockets of air turbulence to be trapped on the underside of the wings and that these pockets somehow support the aircraft at steep angles of attack.

So let's examine in a little more detail how different forms perform in the air.
Kamm Effect

While fluid dynamics says that a teardrop shape is the ideal aerodynamic form, Kamm found that by cutting off / flattening the streamlined end, he could gain most of the benefit of the teardrop shape without incurring such a large material, structural and size problem.
Now let's see what the purpose of wing-tip devices is and how they affect flight.

“The wingtip devices increase the lift generated at the wingtip, and reduce the lift-induced drag caused by wingtip vortices, improving lift-to-drag ratio. This increases fuel efficiency in powered aircraft, and cross-country speed in gliders, in both cases increasing range. US Air Force studies indicate that a given improvement in fuel efficiency correlates directly with the causal increase in L/D ratio”.

“Such devices increase the effective aspect ratio of a wing, with less added wingspan”.

(\text{http://www-reference.com/browse/wiki/Wingtip_device})

Flight tests made and without winglets showed that the winglets increased range by about 6.5 percent and also improved directional stability. They also play a role in interrupting harmful wingtip vortices. This decreases the amount of lift-induced drag.
**Gliders** have long spans to increase aspect ratio, which makes them stay in the air longer. However, high aspect ratio has some drawbacks. Longer span places air loads farther outboard, resulting in greater bending moments, being placed on the wings. To resist these bending moments, we need heavier supporting structures.

Wingtip devices can help to give the same result as increasing the aspect ratio of a wing without physically doing so.

The aspect ratio of a wing is the wingspan squared divided by the area of the wing. It is the distance a plane will glide divided by its altitude. The glider has a larger aspect ratio than a conventional plane, thus can stay in the air longer.

Below is a quick illustration of the relationship between Wing Span, Wing thickness and Glide Distance:
“Drooped tips give the span-wise flow a somewhat downward flow around the tip. The result is a formation of the vortex farther outbound, rather than at the actual wingtip. Because it is the distance between the tip vortices that determines the action of the vortices, the wing behaves in this respect as if it were wider in span, hence the effective aspect ratio is increased without physically increasing it”.

(Smith H.C., The Illustrated Guide to Aerodynamics)
Glide Ratio Comparison

Cessna - 152

36
32
11
12
9
4.5
0.8
0.368
We covered till now airfoils, wingtip devices and their influence on flight. However the general wing form (plan face) has also a major influence on how the airplane behaves in the air. The different wing designs below, each serve different functions.

For example Delta wings have reasonable performance at subsonic and supersonic speeds and are good at high angles of attack. Forward-swept wings are high performance wings. Sweptback wings are made for high speeds and sudden change in speeds. They stall at low speeds. On a rectangular wing, air turbulence affects the central part of the wing instead the wing tip, making them more stable.

**Wing loading** is the loaded weight of the aircraft divided by the area of the wing. It is a very important feature that strongly influences aircraft performance.

The faster an aircraft flies, the more lift is produced by each unit area of wing, so a smaller wing can carry the same weight in level flight, operating at a higher wing loading. Correspondingly, the landing and take-off speeds will be higher. The high wing loading also decreases maneuverability.

Larger wings move more air, so an aircraft with a large wing area relative to its mass (i.e., low wing loading) will have more lift at any given speed. Therefore, an aircraft with lower wing loading will be able to take-off and land at a lower speed (or be able to take off with a greater load). It will also be able to turn faster. Wing loading also affects gust response, the degree to which the aircraft is affected by turbulence and variations in air density. A small wing has less area on which a gust can act, both of which serve to smooth the ride. So for example for high-speed, low-level flight (such as a fast low-level bombing run in an attack aircraft), a small, thin, highly loaded wing will be preferable. **Gliders and small aircrafts such as the Cessna-152**, will perform better when wing loading is reduced.
There is also a strong relationship between the Center of Gravity (CG) and form of the aircraft, which influences the stability of the whole aircraft.

Each airplane has a different form. Both the form of the profile and the face of the aircraft can have an effect on its stability. Considering how CG affects stability is important to know as this will affect the form, location and weight of the new safety devices among many other factors to be considered.

The location of the power-plant affects the CG in a big way, as a lot of weight is located there. Below is a comparison between a Cessna-152 and a twin engine aircraft, where the engines are mounted on the wings:

**Cessna - 152 - Fuselage Mounted Engine**

**Wing Mounted Engines**
Below are some more comparisons of Cessna-152 with other aircrafts. Structural elements are shown and what their influence is on the location of CG and stability.

1. High-Wing versus Low-Wing Aircraft

Low Wing Aircrafts are more stable because the CG is lower to the ground

2. Nose-wheel Planes versus Tail-wheel Planes

Tailwheel planes are most easily to flip over. Having a nose gear provides at least some initial protection

3. Narrow Wheel Base versus Wide Wheel Base Planes

Aircrafts with a wider wheel base are more stable because the CG is lower to the ground. Cessna's have a wheelbase of around 7 feet, while Piper's wheelbase is around 10 feet wide, which makes them more stable.
Until now all the aircraft we discussed were with one pair of wings. But there are very important and interesting changes happening during flight when we double the wings. Below such planes are shown. They are called Bi-planes.

So what is the big deal about them?

Aircraft built with two main wings can usually lift up to 20% more than can a similarly sized monoplane of similar wingspan.

Most successful early aircraft were biplanes, in spite of considerable experimentation with monoplanes. Only later with high speed requirements did the monoplane wing gain popularity.

The sesquiplane (see above) has one and a half wings and the lower is significantly smaller than the upper. This further reduces interference drag and if the wings are placed at least one chord length apart interference drag is eliminated. In addition if one wing is placed slightly in front of the other pair, not exceeding 95% stagger, and if wing struts can be somehow eliminated this will make the airplane fly even better.

However any structure that remains fixed in an aircraft means that the aircraft is able to do one thing well, but is unable to execute other parts of a mission as well as another aircraft without the fixed structure is able to do. So what can be done about it?
**Morphing Aircraft** are multi-role aircraft that change their external shape to adapt to a changing mission environment during flight. This creates capabilities not possible without morphing shape changes. Morphing technology is researched to be applied to wings and make them be able to change shape during flight.

However from a technical point of view four elements must be combined to work together to create a morphing wing:

1. Sensors
2. Control Systems
3. Actuation mechanisms
4. Efficient Power

However such a technology is far too expensive to be installed on an old Cessna-152.

Also it will require power and as research indicated, power failure is highly common in Cessna airplanes. What will be the point of having such an expensive hi-tech on board, when it might be unusable when it is needed?

**Advantages of combining qualities of:**

- Fixed single wing airplanes
- Hi-tech morphing wings
- Fixed wing Bi-planes

Adaptable to need, but lower in cost wings that can function without power.
Below are examples of patented flexible wing systems. However they are fairly complicated and even though they might be great to be used on newly designed aircraft, such ideas cannot be retrofitted and function on an already designed airplane, without changing major structural components. A simpler solution has to be found.
4.2 The Physics of the Impact

The severity of an impact and injuries sustained by the pilot, in our current world of aerodynamic rules, depends on how energy was absorbed and transferred during a hard landing or crash. From an energy absorption point of view, what the pilot would enjoy to have are structures that gradually deform, then progressively fail, never completely giving into the aggressive forces. The energy used to deform the structure is energy that won’t find its way into the pilot. Pure strength, however, isn’t the answer. A structure can easily be too strong! A perfectly rigid structure is as bad as a flimsy one. A structure that is so strong it doesn’t deform will pass all the impact energy directly to the pilot.

What the pilot needs is a structure with a deceleration rate that occurs over a long enough distance that he won’t get hurt. If he comes to a rapid halt in two feet, that’s one thing. If he has ten feet to slow down in, that is a totally different situation.

If light airplanes were all constructed of the same material as the large airliners or even better—the military aircrafts, they would indeed have plenty of protection because of their slower speeds and lighter weights. However, most small aircraft use much lighter material, which deflect much easier, thereby ablating less energy. Besides that there are structural points in airplanes that fail immediately during impact, causing the entire structure to collapse and absorb very little of the impact energy. It is important to consider how kinetic energy can be absorbed better by considering forms and materials suitable for controlled and predictive energy absorption.

Crash events are usually highly non-linear and may involve material failure, global and local structural instabilities and failure of joints. Also, strain-rate and inertia effects may play an important role in the response of the structures involved.
Change in momentum \((mv) = \text{Impulse} = \text{Force} \times \text{Time}\)

For an object brought to rest, the impulse is the same no matter how it is stopped. But if time is short the force will be large.

Increasing the duration of the impact will reduce the possibility for injury.

Above is an example showing the change of momentum that occurs over a long time so hitting force is small.

Here the change of momentum occurs over a short time, so hitting force is large increasing the risk of injury.

**The Shock Wave during an Impact**

The harder the landing the stronger the shockwave is felt both by the aircraft and the pilot and the higher the risk of damage and injury. Structures and materials together can play an important role in cushioning the impact.
Below is a real life example illustrating the idea that **increasing the duration of the impact will reduce the possibility for injury**. Of course, in this scenario, pure luck saved the pilot. However, there is possibility to design a safety device that can actually use similar principles to cushion hard landing or crash.

**Increasing the duration of the impact will reduce the possibility for injury.**

Plane had no time to return to the runway, the pilot of this Cessna 182 was in trouble. Luckily, he found a whole pile of portable toilets, and the crash landing on top of them probably saved his life.
The pilot, whose identity has not been released, was able to walk away apparently unharmed.

**G-Force**
A "G" is a measurement of force that is equal to the force of gravity pushing down on a stationary object on the earth's surface. Gravitational force actually refers to an object's weight (Force equals Mass times Acceleration, or \( F = ma \)). An aircraft flying level at low altitudes experiences 1G. Extra G-forces in any direction can be artificially created by sudden changes in velocity or in the direction of motion.

**Physical Effects of G-Forces**
Human bodies can withstand approximately 9 or 10 positive Gs or 2 to 3 three negative Gs. Exceeding positive G limits for longer than that causes blood to collect in the lower part of the body and torso. The brain and retinas receive less blood, and therefore less oxygen. Eventually, vision turns gray, followed by tunnel vision and pilot blackout.

Excessive negative Gs have a similar effect, except that blood pools in the brain and upper torso. This causes the small capillaries in the eyes to swell, creating a red-out effect.
3.3 Analysing Structures & Forces

“Structural crashworthiness” concerns absorption of kinetic energy by considering designs and materials suitable for controlled and predictive energy absorption. In this process, the kinetic energy of the colliding bodies is partly converted into internal work of the bodies involved in the crash.

A structure like a triangle or square or polygon is stronger than a sphere at its edges and corners. But its sides are weaker than a sphere because they have no inner support.

It’s harder to crush a triangle by pressing down on its corners than it is to crush a sphere, but it is easier to crush the triangle by pressing down on its side, than crushing the sphere.

In other words angles concentrate the strength of the structure at a point. So a sphere has even strength, whereas a triangle or square has concentrated strength points.

A sphere is the strongest shape because sharp corners are regions of weakness. So as a compromise, boilers, gas cylinders and the pressure hull of a submarine have rounded ends. Bulk gas under pressure is often stored in large spherical tanks. The first bathyscaphes were spherical, even though this made them uncomfortable for the occupants. A sphere distributes all the compression or tension, depending on whether the high pressure is outside or inside, equally, giving maximum strength.

Buckminster Fuller was a great designer who’s structures were inspired by natural formations and laws. His designs are very much based on the forces of compression and tension applied in highly creative ways. His philosophy was to do “More with Less”. His designs inspired me in this project.
Below three basic structures are shown and how they deform with increased weight. The arrows show the forces of tension and compression.

1. The weight pushes down on the rectangle and causes the top side to bend.
2. This shape is the first to break.
3. When an arch is pushed too hard, the sides start to spread apart.
4. This shape is the first to break.
5. The weight presses down on the arch and is spread outward along the curve to the ground below.
6. The weight causes the top two sides to squeeze together and the bottom side to pull apart.
7. Unlike the rectangle, the sides of the triangle did not bend under the tremendous weight.
8. The arch likes to be pushed and squeezed. The weight pushes this arch into a stable, tightly squeezed shape.
9. The triangle is still standing because the pulling force in the bottom side is balancing the pushing forces in the upper sides.
10. The third side stretched so much that it snapped in two.
Cross-Section and Cross-Sectional Area

One of the most important characteristics affecting the strength of a structural member is its cross-section. A cross-section is the two-dimensional shape you see when you look at the end of a member.

- As the cross-sectional area increases, the tensile strength increases in direct proportion to the area.
- Tensile strength depends on the type of material the member is made of. Every material has its own characteristic strength, measured in units of force per area (for example, pounds per square inch or newtons per square meter). The yield strength of carbon steel is 36,000 pounds per square inch. Other types of steel with yield strengths of 50,000 pounds per square inch and higher are common. The tensile strength of a member can be calculated by multiplying the tensile strength of the material by the cross-sectional area of the member.
- Tensile strength does not depend on the length of a member.
- Tensile strength does not depend on the shape of the cross-section. If we tested a hollow tube or circular rod with a cross-sectional area of 1 square inch, we would find that its tensile strength is exactly the same as the 1" x 1" square steel bar.
- Buckling is a failure that occurs when compression causes a member to suddenly bend sideways, perpendicular to the direction of the applied load. Buckling is the most common failure mode for structural members in compression.
- Compressive strength depends on the length of the member. For all five specimens, increasing the length causes a substantial reduction in the compressive strength.
- Compressive strength depends on the shape of the cross-section. A hollow tube has a substantially higher compressive strength than a solid bar, for a given length and cross-sectional area. A square bar has somewhat higher strength than a rectangular bar with the same area.
- Increasing the cross-sectional area of a member increases its compressive strength. Note that, unlike tensile strength, the compressive strength is not proportional to the cross-sectional area. (For example, doubling the area generally will not double the strength.)
- Compressive strength depends on the material the member is made of. Stronger, stiffer materials have higher compressive strength than weaker, more flexible ones.
Below in an example of how forces act on an aircraft’s wings. However every part of the structure is subject to changing forces acting on it both during flight and landing. This is why everything in an airplane must be designed carefully taking the effect of the forces into consideration.

Strain occurs when a physical body is deformed under the action of applied forces. This may be a positive or negative thing.
Every airplane type has unique characteristics in terms of form, weight, center of gravity location, etc. All these influence what load factors (which are related to the forces), the airplane can take without structural failure to occur. If certain speed are exceeded structural failure occurs. The pilots are aware of the limits. Different speed values must be observed depending on what is performed. For example, a different speed value applies during maneuver than during normal level cruise, or a different speed must be observed during landing than during cruise. Below is a graph illustrating this.
4.4 Different Materials = Different Characteristics of Structures

The evolution of the airplane has followed the development of structural materials. The first airplanes were made primarily of non-metal materials such as wood, then came the era of the all-metal airplane, and today we have aircraft that are made from a combination of metal and high-strength plastics and airplanes made almost entirely out of plastics in their construction. Composites, which are reinforced plastics have come a long way. Depending on the reinforcement, the resin and the matrix structure, the properties of a certain structure can be changed. Engineers have to carefully consider under what forces a structure will be subjected, in what environmental conditions it will operate, what is the expected performance, the cost ceiling, and many other considerations, before deciding on the right material for the purpose. However no matter how well something is engineered, it still has to be prototyped and tested and data analyzed after that, for to make the final decision. Often choosing the right material may mean making compromises between opposing qualities. For example:

- **High Rigidity**: More rigid but less elastic
- **Medium Rigidity**: Medium Elasticity
- **High Elasticity**: More elastic but less rigid

Below and on the next page are examples of materials and their unique qualities that makes them suitable for one thing but unsuitable for something else. Choosing the right material is a complicated procedure, both for engineers and designers. Also some materials make some forms possible, while others cannot. Material, form and production methods are always closely related.
<table>
<thead>
<tr>
<th>Intelligent Materials:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D3o</strong></td>
<td>D3o is a material made with intelligent molecules. These flow freely as long as they are not subjected to pressure, but the second they receive a blow or impact they lock together. The material's soft and flexible under normal condition but instantly locks and become hard and shock-absorbent on impact. The D3o material does not harden when it is subjected to impact, but the effect is comparable with a net that absorbs and distributes the force.</td>
</tr>
<tr>
<td><strong>EIS W50 Energy Foam</strong></td>
<td>EIS W50 was developed in accordance with higher standards governing the materials that can be used for head and body protection in various motorsports sanctioning bodies. It is widely used in headrest applications as occupant seating systems. EIS W50 is a resilient foam, meaning it will not stay deformed after a crash but will return to its original shape, keeping you protected for multiple impacts in a crash.</td>
</tr>
<tr>
<td><strong>Texilar</strong></td>
<td>Texilar is used in light armoring systems for vehicles, as well as trauma reduction and blast-protection systems. The product range also includes special laminates and panels for other industrial applications (interiors of planes, ships, and trains), including epoxy and phenolic resins with high fire resistance and low smoke emission characteristics.</td>
</tr>
<tr>
<td><strong>Kevlar</strong></td>
<td>The aromatic ring gives Kevlar thermal stability, while the para structure gives it high strength and modulus like nylons. Kevlar filaments are made by anchoring the precursor through a spinnable. The Kevlar precursor is very stable both chemically and thermally. Today, there are three grades of Kevlar available: Kevlar 29, Kevlar 49, and Kevlar 149. Kevlar® brand fiber is an innovative technology from Du Pont that combines high strength with lightweight to help dramatically improve the performance of a variety of consumer and industrial products.</td>
</tr>
<tr>
<td><strong>Nitinol &amp; Shape Memory Alloys</strong></td>
<td>Shape Memory Alloys are metals that can change shape, change position, roll, compress, expand, bend or turn, with heat as the only activator. Key features of products that possess this shape memory property include: high force during shape change; large movement with small temperature change; high permanent strength; simple application, because no special tools are required; many possible shapes and configurations; and easy to use - just heat. Most SMA's have poor fatigue properties compared to steel however.</td>
</tr>
<tr>
<td><strong>Carbon Fiber</strong></td>
<td>Carbon fiber has less tensile strength than kevlar but a higher tensile strength than fiberglass. Carbon fiber is on average approximately three times stiffer than either fiberglass or kevlar depending on the type, while being more expensive than fiberglass but less expensive than kevlar.</td>
</tr>
<tr>
<td><strong>Ap Nano-Spheres</strong></td>
<td>IF nanospheres have up to about twice the strength of the most impact-resistant materials currently used in protective armor applications like boron carbide and silicon carbide, and are 4-5 times stronger than steel. The material was subjected to severe shocks generated by firing shots at it at impact velocities of up to 1.5 km/second. The IF nanospheres withstand the shock pressures generated by the impacts of up to 250 tons per square centimeter. This is approximately equivalent to dropping four diesel locomotives onto an area the size of one's fingernail. The IF nanospheres are so strong that after the impact the samples remained essentially identical compared to the starting material.</td>
</tr>
<tr>
<td><strong>Temper (Memory) Foam</strong></td>
<td>Tempur® is a high-tech foam originally developed by NASA for use in astronaut seating to absorb the high G-forces of space vehicle launch. Tempur adapts to body shape in response to body heat and pressure and thus spreads the pressure uniformly and comfortably.</td>
</tr>
<tr>
<td><strong>Aluminum Foam</strong></td>
<td>Super tough HDPE</td>
</tr>
<tr>
<td><strong>Specialty Steels</strong></td>
<td><strong>Nickel-Base Alloys &amp; Superalloys</strong></td>
</tr>
</tbody>
</table>
5. The Aircraft

5.1 Flight Phases and Risk Exposure

Not all flight phases are equal both in terms of exposure to risk or actual accidents occurring. In addition, the pilot workload and level of exhaustion also differ during various stages of flight. This is important to consider when designing safety devices, because the potential dangers are different during the different stages and the pilot's physical and mental condition does not remain constant throughout the whole trip either. It is for example a bad idea to make a device that needs additional pilot concentration and control during the most exhausting part of the trip.

The diagram below shows the changing safety margin during the different stages of flight as his capabilities decrease because of physical and mental exhaustion. Small aircrafts differ than big airliners. It is easier to fly a big airliner, because during most part of the trip, the aircraft is working on autopilot. In small aircrafts however, the pilot can never relax and has to constantly monitor other aircrafts in close proximity and also make sure one doesn't go off course and get lost, in addition to many other activities.
Above we can see the different percentages of both actual accidents happening and exposure to risk of accidents. As we see the percentages do not correlate for exposure and accident occurrence.

During Cruise an actual accident happening is low, however this is the stage where most problems develop which later during landing may cause an accident.

During Landing, there is less exposure to risk while still in the air, but a very high probability of an accident happening during Touchdown.
On the previous page we discussed accidents by percentages. This gave us a general overview of the different nature of the phases during flight in terms of dangers or actual accident occurring.

However how many accidents do really happen? And how many of those accidents are severe and end in death? These questions are important to consider as they may direct me as designer to narrow down the areas where most problems do happen. Since I am designing for a Cessna Aircraft the data collected below is for Cessna Aircraft Accidents.

<table>
<thead>
<tr>
<th>Decade</th>
<th>Deaths</th>
<th>Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>70's</td>
<td>2196</td>
<td>15,784</td>
</tr>
<tr>
<td>80's</td>
<td>1858</td>
<td>11,624</td>
</tr>
<tr>
<td>90's</td>
<td>1247</td>
<td>7,585</td>
</tr>
<tr>
<td>00's</td>
<td>850</td>
<td>4,579</td>
</tr>
<tr>
<td>Total</td>
<td>6151</td>
<td>39,572</td>
</tr>
</tbody>
</table>

As we can see the number of non-death related accidents greatly outnumber the fatal ones. Also many accidents that are minor are actually never reported and thus are not included in the data above. However they are quite numerous as many pilots indicate and I myself had observed a few incidents happening, while I was taking my flight lessons.

Accidents are much more common than fatalities. Many minor accidents are not even reported. 

A minor accident can easily spin out of control and turn into a life-threatening situation.

A minor accident can easily spin out of control and turn into a life-threatening situation. Also accidents can cause injuries and damage to the aircraft, resulting in thousands of dollars to be payed to insurance companies and medical care.
5.2 Severity of Accident Matrix - A Human / Machine Classification

Severity of accidents vary.
For this reason it is important to classify accidents, because this will help us to better understand where
to focus design efforts and also what the design limitations and boundaries of the new safety device
will be. Accident severity can be divided into two categories:

Human and Machine

Even though there is often a positively proportional relationship between the degree of severity of the
accident of the machine and the degree of injuries sustained by the human inside, this is not always
the case. Accidents could be negatively proportional too. For example the machine may sustain much
damage, but the individual inside the vehicle may sustain very minor injuries and the opposite. See
diagram below for the different combinations.
Here are some examples of what constitutes severity of injury and level of damage to the aircraft during an accident.

**Severity of Injuries**

1. **Minor**
   - Injuries requiring basic medical aid that could be administered by paraprofessionals. These types of injuries would require bandages or observation. Some examples are: A sprain, a severe cut requiring stitches, a minor burn (first degree or second degree on a small part of the body), or a bump on the head without loss of consciousness.

2. **Serious**
   - Injuries requiring greater degree of medical care and use of medical technology such as x-rays or surgery, but not expected to progress to a life threatening status. Some examples are: Third degree burns or second degree burns over large parts of the body, a bump on the head that causes loss of consciousness, fractured bone, dehydration or exposure.

3. **Fatal**
   - Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. Some examples are: Uncontrolled bleeding, punctured organ, other internal injuries, spinal column injuries, or crush syndrome.

**Level of damage to the aircraft**

1. **Slightly Damaged**
2. **Substantially Destroyed**
3. **Destroyed**
Below I have taken the most common accident combinations and came up with some quick scenarios for each.

<table>
<thead>
<tr>
<th>Accident</th>
<th>Machine</th>
<th>Human</th>
<th>Possible Scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 - 3</td>
<td>Destroyed</td>
<td>Fatal</td>
<td>Head-on crash eg after trying to glide the plane to crash land but it hits a tree or building or hard object. Also if crashing on the ground head on. Or if after impact spark causes fire.</td>
</tr>
<tr>
<td>3 - 2</td>
<td>Destroyed</td>
<td>Serious</td>
<td>Very hard landing on an unsuitable terrain. The engine separates on impact but fire luckily doesn't occur, but serious injuries are still caused by the severe impact.</td>
</tr>
<tr>
<td>3 - 1</td>
<td>Destroyed</td>
<td>Minor</td>
<td>Very unfavorable crash landing conditions but well designed aircraft absorbs and dissipates impact force gradually. Or first impact wave was absorbed by other elements first eg the wings prior to reaching the pilot in a violent way.</td>
</tr>
<tr>
<td>2 - 3</td>
<td>Substantially Damaged</td>
<td>Fatal</td>
<td>Landing terrain very difficult and no safety protection for pilot whatsoever exists. Serious spinal injury or head injury or bodily damage through other aircraft elements cause death.</td>
</tr>
<tr>
<td>2 - 2</td>
<td>Substantially Damaged</td>
<td>Serious</td>
<td>On take of seat rails snap and pilot pulls on the yoke causing plane to get out of control and crash quickly because pilot has little time to regain control. This scenario often ends in death or very serious injuries.</td>
</tr>
<tr>
<td>2 - 1</td>
<td>Substantially Damaged</td>
<td>Mild</td>
<td>Crashing quite unfavorably but pilot protected by safety device and able to escape wreckage fast. If he is not injured but is trapped this can result in a fatality (due to fire, smoke).</td>
</tr>
<tr>
<td>1 - 3</td>
<td>Slightly Damaged</td>
<td>Fatal</td>
<td>Plane crashing into sea, but pilot unable to open door because stuck and drowns. Or a jammed door in a crash landing on the field which was glided well, but jammed door prevented pilot from escaping.</td>
</tr>
<tr>
<td>1 - 2</td>
<td>Slightly Damaged</td>
<td>Serious</td>
<td>Nose gear collapse after a harder landing, but shoulder harness rips during impact and pilot hits his head on the yoke or some other hard object.</td>
</tr>
<tr>
<td>1 - 1</td>
<td>Slightly Damaged</td>
<td>Mild</td>
<td>Nose gear failure, however favorable crash terrain and good protective devices. Engine Failure in air but protective devices help pilot find a better crash terrain and absorb shock on impact in a gradual manner.</td>
</tr>
</tbody>
</table>

During a real crash there may be several injuries throughout the body and the injury rating may be dissimilar throughout the body. The following is statistics published in the American Journal of Forensic Medicine and Pathology by Li, Guohua M.D., Dr.P.H.; Baker, Susan P. M.P.H.

Multiple injuries were listed as the immediate cause of death in 42% of the fatalities, followed by head injury (22%); internal injury of thorax, abdomen, or pelvis (12%); burns (4%); and drowning (3%). Head injuries were most common among children. The majority (86%) died at the scene or were dead on arrival at the hospital. 18% of the victims were reported to have sustained a single injury, with head injury being the cause of death in nearly a third of these fatalities. Blunt injuries resulting from deceleration forces (impact), in particular head injury, are still the most important hazard threatening occupants’ survival in aviation crashes.

**Blunt injuries (non-penetrative) resulting from deceleration forces (IMPACT), are still the most important hazard threatening occupants’ survival in aviation crashes.**

The more the pilot is tossed around during an accident the more the likelihood increases that seatbelts may rip or that the head might get slammed into something. To keep the aircraft stable during an accident is important.
5.3 Accident Scenarios & Predictable Sequence Flow of Damage during a Crash Landing

While I was observing many different accident photos, videos and reports, I found that Cessna’s have certain common crash patterns.

Many accidents begin when the airplane develops problems in the air, such as engine failure or fuel starvation and tries to land often on an unsuitable terrain. Even a suitable terrain however may not be of much help if the approach and landing was done incorrectly.

To provide the necessary balance between longitudinal stability and elevator control, the center of gravity (CG) of the aircraft is usually located slightly forward of the center of lift. This loading condition causes a nose-down tendency in flight, which is desirable during flight. However, during an uncontrolled crash landing the nose tends to go down and often hit first and if the airplane hits the ground at high G-forces and if the angle of landing directs the weight of the airplane forward and overloads the nose gear, it usually collapses after which the airplane often flips over. This is a dangerous situation, because at this point the engine has been hit, the pilot often too and now flipping upside down can cause further risk of sparks to occur as well as more injuries to the pilot. This scenario can happen even during a normal controlled landing, if the pilot fails to land at a suitable speed or angle due to lack of experience for instance, or an environmental factor, causing a hard landing with un-equalized stress to form around structural elements after which they may collapse causing a dangerous chain reaction.

Shown below is a GOOD Landing Scenario and on the next page are some common bad landing scenarios that can be potentially dangerous. The main causes are indicated.
Most Common Badly controlled Landing Scenario

- Engine and/or propeller hits the ground
- Airplane flips over
- Danger of Fire
- Airplane collides with ground Nose Gear collapses
- Airplane approaches at a wrong angle or makes a too fast descent

Engine hits the ground
Airplane slides and comes to rest
Hitting an object happens and is dangerous
Airplane fails to maintain correct angle too much pressure is placed on nose-gear Nose Gear collapses
Airplane approaches runway at correct speed and correct angle

Very Common Bad Landing Scenario

- Overall structural failure occurs often after nose gear collapse
- Airplane approaches at a wrong angle or makes a too fast descent

Very Common Bad Landing Scenario
Below are a few real-world bad landing scenarios that correspond to the scenarios described on the previous page.

Sixty-year-old Ronald Holcomb of Birmingham, along with his Alaskan Husky, were making their way from Detroit to Pellston when the 1966 Cesna 150 he was flying started experiencing engine troubles. The small, single-engine plane crashed minutes before noon on June 28 just off Wilkinson road. Michael Benefiel was fishing with friends at a nearby pond when he first saw the troubled aircraft. “We saw it come over the top of the trees,” Benefiel said. “The engine cut out, spit and sputtered, then the propeller stopped. We knew he was going to try to land.” As the plane came down, Benefiel saw it try to pull up as it neared the ground. The front tire hit a small hill and the aircraft flipped over.

TULSA, OK -- A single engine Cessna was involved in an accident at Tulsa’s R.L. Jones Jr Airport. Captain Michael Baker, Public Information Officer for the Tulsa Fire Department, said the pilot, a student, was the only person on board when the plane lost the nose gear upon landing. The plane’s nose gear, as well as wing and prop were damaged. Baker said no hazardous fluids spilled, even though the plane had about 22 gallons of fuel on board.

A student pilot crashed a Cessna 152 at Gillespie Field in El Cajon. Apparently it was the student pilot's second solo and while practicing his touch and go. The C152's nose gear collapsed and the prop struck the pavement, and fire sparked.
On the previous pages sequences of bad landing scenarios were shown, that lead to first a damaged aircraft and second when the force hits the pilot - to injuries. Below, using a common bad landing scenario, I have also added what happens to the pilot in a sequence as the crash progresses, that could lead to death. For this I divided the crash into three categories: Prior to Impact - On Impact - After Impact

- What happens to the Airplane
- What happens to the Human

Human Collision follows after Airplane Collision
Airplane approaches at a wrong angle or makes a too fast descent
Airplane collides with ground Nose Gear collapses
Airplane flips over
Engine and/or propeller hits the ground
Danger of Fire
Danger of smoke Inhalation

After Impact  On Impact  Prior to Impact
The point at which the Human Collision occurs, is usually the critical phase for survival as previous data indicated. Below I looked closer of what actually can happen to a body after impact that could cause the injury or death.

All systems and organs are important in the human body for a healthy life. However some parts of the body once they get damaged, can result in immediate death or a life threatening situation which needs immediate medical intervention. Below the most important regions are shown and how impact can affect them.

- The Nervous System which includes the Brain and the Spinal Cord is one of the most important regions that need protection. Impact may result in immediate death or permanent brain damage or paralysis.

- The Cardiovascular and Respiratory Systems which include the heart and the lungs are also essential for survival. Impact may result in ruptured arteries and obstruction of air paths and death.

- One of the functions of the Skeletal System is to protect certain organs from impact. For example the ribs protect the heart, the spinal bones protect the spinal cord, the skull protects the brain. However bones can break easily when impact is strong.

- Damage to the Limbs (Arms, Legs) is not desirable however it does not pose an immediate danger to life.
Below is a little bit of **Brainstorming** for the complete sequence flow of an accident.

### Prior to Impact

**Problem encountered in Air** (eg. engine failure, fuel starvation...)

Automatic fix itself. Redundancy systems. Aircraft becomes a helicopter. How can a helicopter work without power? Two separate power sources? Wind, sun powered blades... Device identifies problem and gives instructions. Airplane changes form and acts as something else that can land softly. Protective shield using air? Using magnetism? Balloons? Balloons with air or rubber? Heavy parts of the plane separate to reduce weight. Pilot lands only with cockpit and a parachute. Airplane changes form and becomes a good glider. Morphing? Intelligent skin? Structure changes and merges with another and thus changes function. Using the air as water - act as ship or submarine at sea. Think of the sphere and other forms. Form affects function. A sphere and pilot fixed onto tension strings that absorb shock when sphere touches ground and bounces. Something happens to the plane to keep it longer in the air - flying without power. Pilot uses microwaves before ground impact to make a controlled landing. Living airplane?

### On Impact

**Airplane Collision**

A deformable exterior that adapts to the impact? Invisible impact resistance? Engine release button to drop engine seconds prior to impact. Should this be automated or human controlled? If automated sensors could be used to detect abnormal air speed and activate it. What about electromagnets? Need power source. On crash-landing pilot must shut down all power to prevent sparks, so how could it work without increasing risk of sparks? Air bags that can withstand high temperatures to be installed around the engine? Or to inflate outwards to minimize severity of head-on crash? Could airbags be installed in other places too? What shapes can they have and how function changes? Cockpit compartment to be designed to withstand collision better through designing crumple zones on high impact areas. Landing gear that absorbs more shock and could also have extra functions that would activate on impact like airbags...The firewall area of the plane - can it be improved? For eg to support dangerous equipment more safer and form to aid in reducing impact? Rearranging major components eg putting engine somewhere else? Nanotechnology materials eg ApNano Spheres embedded in the firewall? More than one firewall?

**Human Collision**

Seat to absorb vertical shock and forward shock. Better seatbelts. Intelligent materials? Invisible strings For vertical shock how about materials with embedded structures? Or a mechanical device used on landing gears to absorb shock? The skin of aircraft itself can morph and become the shock absorber. Or one structure changes and merges with another and becomes a new device...Can Seats provide better protection from side injuries of the head? Fixed or activated in emergency? What about air bags under the seat? What about the door and windows? Can they be equipped with air bags? What about when trying to get out. Could there be a way to quickly remove air from the airbags when no more needed so that exit is not obstructed? Can the instrument panel be equipped with airbags? What about the legs? How about airbags that inflate in between layers of materials? Multiple small? What about helmets that pilots an wear for protection?

### After Impact

**Smoke Inhalation**

Smoke inhalation is related to fire. To place device to prevent from smoke may be good, but the pilot needs to escape from the fire. This is a priority. If it will be a smoke protection device it should be independent of the plane. How about using materials which when burning do not cause poisonous fumes and retard fire?

**Fire**

Equip Engine with automatic fire extinguisher or Fire extinguisher inside cockpit. Something that acts like rain around the airplane? Isolate engine better. What about a better firewall? Protective clothing

Making door so that hinge slides outward or is easy to open after crash so that pilot can escape fast. Adding weak points? Device that helps pilot to get out from crash site if injured (something that requires less strength) Preventing sparks to occur in the first place? Pull-out mechanism for the rubber gasket of window so it can be pushed out easily and escape.
Cessna-152 has a fixed tricycle gear. The nose gear is fixed to internal struts to either the engine or firewall. With repeated landings, especially when students train and land at wrong angles, putting pressure on the nose gear instead of the landing gear, this causes much un-equalized stress to form and thus cracks to appear around structural elements, which often go unnoticed, until it’s too late.

Often a bad landing can cause the nose gear to fail, even if it has no prior damage. This again is most often caused by students and also experienced pilots if outside factors are unfavorable, for example the landing terrain is rough or wind conditions are bad.

After a nose gear collapse, especially a sudden collapse, chain events usually follow which, first cause damage to the aircraft and then when the shock wave reaches the pilot, internal and other injuries may result.

Redesigning the tricycle gear system or the nose gear itself, will require a major structural change, which will be too expensive and will require a redesign of the whole aircraft as all equipments are connected internally and engineered over many years. This will be beyond what Cessna Company is willing to pay for improvements to be made on an already designed model, which is also old. However the safety of pilots is also of major concern and since this aircraft is one of the most popular used by inexperienced student pilots to train in, it is necessary to improve on this part of the aircraft, making it more fail-prove. Or if it fails to at least prevent a sudden failure.
Here is a small report from a pilots resources website (www.pilotfriend.com), that also reinstates the points that I mentioned:

“Aircraft damage due to landings is mostly accumulative. Occasionally it happens all at once but usually it is accumulative.

The accumulative damage mostly occurs to the nose gear. When the nose wheel becomes a part of the initial landing contact it becomes life limited. Every compression of the strut loses some air and perhaps oil. If the strut is not cleaned prior to every flight the accumulated oil and dirt act like sandpaper on the ‘O’ ring. After a number of nose wheel compression cycles the strut will become flat and knock against the wheel even when taxiing. Every subsequent landing causes the shock of the nose wheel landing to be transmitted into the firewall and the engine mounting. Now, the damage is not just to the gear but in the engine and the aircraft airframe. I recently (February ’94)saw someone taking the NRI 172 and make somewhere between 4 and 6 touch-and-go’s. Every one of the ‘landings’ was flat. Not once was the nose wheel held off the runway for even a moment....

A pilot may have erroneous perceptions as to what makes a good landing. Maybe, there is a problem with knowing aircraft attitudes. Is establishing a stabilized approach at a constant airspeed the problem? Very possibly, it is caused by a situation beyond the pilot’s experience.....”

Below are two more real world accident scenarios that illustrate the problem

Improper flare leads to nosegear collapse
Posted by Meg Godlewski · June 24, 2009
This June 2007 accident report is provided by the National Transportation Safety Board. Published as an educational tool, it is intended to help pilots learn from the misfortunes of others.

The 43-hour student pilot was returning from his first solo cross-country flight. He told investigators that he misjudged the airplane’s altitude above the runway and flared too early. The Cessna dropped 10 feet to the runway. The pilot did not initiate a go-around. The nose gear collapsed. The pilot attempted to taxi the airplane off the active runway without success.

Aircraft Incidents and Accidents
Tuesday, December 21, 2004
HENDERSON, TEXAS 75654

While on a maintenance flight, a rough running engine developed and the pilot elected to make a precautionary landing at Rusk County Airport, Texas. After a "normal" landing on runway 16, he back taxied and was turning onto taxiway bravo, when the airplane made an uncontrolled right turn, followed by the collapse of the nose landing gear. Examination of the aircraft revealed that the nose gear trunnion lug had fractured, resulting in the nose landing gear collapse and structural damage to the nose gear well.
5.6 Major Structural Components of the Cessna

**Wings**
- Fuel Tanks
- Spar
- ribs
- Skin
- Wing Tip
- Stringers
- Aileron
- Wing Flaps

**Fuselage**
- Stressed Skin
- Bulkhead
- Formers
- Wing attachment
- Firewall
- Cockpit
- Doors
- Windshields

**Empennage**
- Vertical Stabilizer
- Horizontal Stabilizer
- Rudder
- Elevator
- Trim Tabs

**Powerplant**
- Propeller
- Firewall
- Engine
- Cowling
- Nose Gear

**Gear System**
- Three Wheels placed in a tricycle arrangement.
5.7 Analyzing Important Structural Components and Sub-Components

We saw in previous sections of this chapter, how the most common crash scenarios start with nose gear failure on landing then a damaged power-plant, that can lead to many more complications. The nose gear is part of the powerplant as we will see below. So let’s examine what actually happens inside the power-plant beneath the skin of the airplane.

**Powerplant Components that can fail after a Nose Gear collapse**

<table>
<thead>
<tr>
<th>Arrangement of Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>The air box for instance, shown on the left, whose function is to take warm air from inside the engine and warm the cockpit. The opening is at the top and its position makes it easy for contaminants to enter. Fuel lines may be damaged during a crash and poisonous materials to find an entry to the cockpit.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fastening of subcomponents to major structural components. On the left is an example of how the engine struts are fastened to the firewall to hold the engine in place. These however may crack during a crash or even a hard landing after the nose gear fails. This is in parts because welded parts create un equalized stress. Also fittings are flared eg the fuel line that is fitted to the firewall. This flare causes cracks to form behind the flare because of stress and the material is thin.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>When components collapse other components can get damaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>The battery shown on the left weights from 20-30 pounds. When it collapses because of the impact it damages important components that are running from the engine to the firewall.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location of the nose gear:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- On the struts that support the engine</td>
</tr>
<tr>
<td>This is considered the better design of the two. However even with this can cause cracks to occur at the welded parts during harder landings.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>General design of nose gear</th>
</tr>
</thead>
<tbody>
<tr>
<td>The nose gear is easy to collapse. After that the whole impact is on the engine increasing the likelihood of fire to occur. It also collapses backward and this goes right into the engine damaging other components and setting the whole aircraft out of balance.</td>
</tr>
</tbody>
</table>

Steering rod ends can also get damaged at the fixtures. Shimmy dampener can get worn out fast and the shimmy motion will start putting stress on the landing gear.

continued on next page
Powerplant Components that can fail after a **Nose Gear collapse**

**Cowling**
It has very limited shock absorption capability. The structures inside is what increases strength. The opening when fully installed is also too small, so proper inspection cannot be carried out as required from pilots prior to each flight. Very little is visible. Only when something seriously goes wrong the mechanic will be able to open the whole structure. If some damage has occurred to the nose gear it may go unnoticed.

**Engine & Propeller**
When structures inside the engine fail, which often happens after a nose gear failure, the propeller if it is still rotating may hit the ground or other obstacles and cause the plane to overturn. On a fuselage mounted engine the fuel lines pass through the cabin increasing the risk of fire to happen close to the pilot. Also acoustic fatigue contributes to component wear-out inside the engine compartment.

**Firewall**
Shape and also the strong material (steel) creates sudden shock during impact rather reduce over longer time interval. The sharp lower corner as well as the perpendicular structure tends to dig into the ground during impact after a nose gear collapse, stopping the aircraft dangerously fast.

Main Reasons for **Nose Gear Collapse**

- Formation of Un-equalized Stress
  - Sudden or Formed over Time
    - **FAILURE**

- Landing Angle
- Hard Terrain
- Accumulated Damage
The Nose Gear in more detail

Nose Gear examples from other Aircrafts

The Cessna’s use the Tricycle Gear System with a fixed Nose Gear compared to the aircrafts above, to make it more simple and less costly.

The nose wheel is connected to the engine mount or firewall and has an oleo strut to dampen and absorb normal operating loads. The nose-wheel is steerable through 8 degrees either side of neutral and can caster under differential braking up to 30 degrees. It is connected to the rudder pedals through a spring linkage.
Not all airplanes have Nose Gears. So let's compare them to airplanes that do have Nose Gears.

### Airplanes that DON'T have a Nose Gear (Tailwheel airplanes)

#### Main Advantages:
- Tail wheels are much less expensive to buy and maintain than a nose wheel.
- If a tailwheel fails on landing the damage to the aircraft will be minimal. This is not the case in the event of a nose wheel failure.
- Due to the increased propeller clearance on tailwheel aircraft less stone chip damage will result from operating a conventional geared aircraft on rough or gravel airstrips.
- Because of the way airframe loads are distributed while operating on rough ground, tail wheel aircraft are better able to sustain this type of use over a long period of time, without cumulative airframe damage occurring.

#### Main Disadvantages:
Tail wheel aircraft are worse when it comes to "nose-over" accidents.
Tail wheel aircraft generally suffer from poorer forward visibility on the ground, compared to nose wheel aircraft.
Tail wheel aircraft are more difficult to taxi during high wind conditions.

### Tricycle Gear Airplanes

#### Cessna - 152

#### Main Advantages:
- Tricycle gear aircraft are more stable than tail wheel aircrafts
- Tricycle gear aircraft are easier to land
- They are less vulnerable to crosswind.
- Tricycle gears cause less damage to the ground surface when hot gases blow (particularly in jet-powered aircraft). As a result, the majority of modern aircraft are fitted with tricycle gear.
- Having a nose gear gives the pilot better forward visibility.

#### Main Disadvantages:
- Creates more drag
- Require more training time for student pilots to master.
- Expensive compared to tail wheels, but cheaper than retractable gears.
In Chapter 4, we talked extensively about wings when we discussed structures and their behavior during flight. Here is a brief summary of what wings are and do:

- Wings are airfoils attached to each side of the fuselage.
- Wings are the main lifting surfaces that support the airplane during flight.
- There are numerous wing designs, sizes, and shapes, each fulfilling a certain need with respect to the expected performance for the particular airplane.
- Wings are attached at the top, middle, or lower portion of the fuselage.
- The number of wings can vary.

Below is a typical wing of a Cessna. As we can see inside there are a loads of structural parts, that help the wing to carry heavy loads, such as the fuel tanks, as well as carry the entire weight of the aircraft. The ribs determine the shape and thickness of the wing. Ailerons and Flaps help to make the wing more flexible to fit different purposes and make maneuvering possible. Since these are the main lifting structures of the aircraft they have to be able to bear most of the weight, thus must be quite strong. Additional lifting surfaces if added can be much more simple. They will serve as support for the main wings.