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Fault Tree - AIAA DBF

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1 Executive Summary

In the Design Build Fly (DBF) project, we were assigned the task of designing and constructing an airplane capable of completing the DBF competition. Our airplane experienced a failure during practice that threatened its ability to complete this task. While practicing the "rough field" taxi portion of the competition, our airplane fell off the taxiway after hitting some obstacles. In the actual competition, this would disqualify it. We analyzed all of the plane's subsystems and discovered the root problem was a maintenance error: the wheels of the plane were unable to roll due to an overzealous tightening job just prior to the taxi attempt. As a result, the plane's ground maneuverability was greatly reduced. To ensure that this problem will not recur, team members will be instructed to not attach the wheels as tightly and to perform a wheel friction check before each flight.

2 General Description

2.1 Scope of the Document

This document is a failure analysis of the aircraft during practice for its ”rough field” taxi mission in the Design Build Fly (DBF) Competition. A fault tree analysis below examines the wing, landing gear, propulsion, and control subsystems for possible causes. All of the requirements not satisfied due to the apparent problem are listed, and the included fault tree diagram presents the events associated with each potential cause of failure. The analysis provides a breakdown of the failure, revealing the true root causes. A recommendation to avoid this specific failure in the future is given based on the analysis results. Further information on aircraft parts involved in the failure, requirements and specifications not met, and the rules and ”missions” of the competition can be found in the documents provided under the ”Applicable Documents” section.

2.2 Functional Description of the System

During the “rough field” taxi mission, the plane is supposed to travel over corrugated roofing panels and maneuver around wooden obstacles. Such interference simulates conditions which might be found in the bush. Since the apparent failure could be the result of several possible root causes, multiple subsystems needed to be analyzed. Particular areas of interest include the landing gear and wing subsystems, and the interfaces between the landing gear and fuselage, wings and fuselage, wings and power plants, and the electrical subsystems.

The principal purpose of the landing gear in this situation is to absorb the shock caused by the corrugated panels. This subsystem also provides ground clearance and improves plane maneuverability.

Since the plane is not airborne, the wings serve only as a structure. The ground clearance must be higher than the highest obstacle. Additionally, the wings must also help prevent the power plants and propellers from impacting obstacles.

The electrical subsystems must relay commands properly and provide the power to propel the plane over the corrugation, yet also keep the plane grounded.

2.3 Apparent Problem

Requirements not met:

- ***Req 2.2.3*** ground clearance > 3.5 *in*
- ***Req 2.3.2*** must cross corrugated panel successfully
- ***Req 2.4.2*** must endure process of landing three missions w/o incident
- ***Req 2.6.1*** ease of control to unfamiliar user

During practice of the ”rough field” taxi demonstration, the plane got caught on obstacles on the field. As a result of impacting the obstacles, the plane subsequently exited the ”taxiway” simulated by the corrugated roofing panel. Taxiway obstacle impacts can result from multiple causes. As a result, a fault tree analysis was needed to examine all of these possible causes.

Due to the apparent problem, several requirements are unsatisfied. Requirement *Req 2.3.II* requires that the plane must cross the corrugated paneling successfully (e.g. without hitting obstacles or exiting the sides of the paneling). Requirement *Req 2.4.II* states the plane (and, especially the landing gear) must endure the process of landing and/or taxiing without incident. If the problem is due to landing gear failure, this requirement is unsatisfied. Requirement *Req 2.6.I* requires that the plane exhibit a level of ease of control that allows an unfamiliar user to operate the plane with minimal difficulty. Depending on the exact nature of the problem, the incident may be a result, fully or partially, of pilot error. Therefore, it may constitute a failure to satisfy this requirement. Finally, requirement *Req 2.2.III* requires the plane to have a ground clearance in excess of 3.5 *in*. The plane's striking of obstacles may be traceable to ground clearance issues.

3 Applicable Documents

- **DBF rules**
- **Specifications:** used to determine impacted requirements and expected performance levels
- **System/subsystem documentation:** used to determine requirements designed to and the requisite operating conditions
- **Master/system parts lists:** used to track the expected part and/or actual part used
- **Repair/change log histories:** determine what, if any, repairs or changes have been made to the system
- **User manuals, part specifications:** used as references for purchased parts and components
- **Test results:** used to determine prior compliance/non-compliance of system with set requirements

Root cause analysis of the incident requires investigation of each potential failure point. During the course of this investigation, the team's **Design Specifications** may be used to determine the expected performance of the aircraft. In addition to this document, the **System and Subsystem Design Documentation** may be consulted. These documents may help clarify the actual requirements each subsystem was designed for and under what conditions they were expected to function properly. It will also be necessary to examine the **Master Parts List** and **Subsystem Parts Lists** to verify the sourcing details of parts under investigation and uncover if any substitutions were made during construction of the plane.

Once the possible failure points have been narrowed down to a few parts, **User Manuals** and **Manufacturer Specifications** will be critical to determining whether the parts were installed correctly and whether they were exposed to environmental conditions that they were not designed to handle. **Repair Logs** and **Change Logs** track the lifespan of the parts and subsystems, aiding in determining whether the root cause was degradation due to age. Information gathered from these documents will help investigators to understand how adjustments made after completion of initial construction may have affected the integrity of the produced plane. The team's published **Test Results** are also a useful source of information to confirm prior levels of compliance or non-compliance with the design requirements.

4 Fault Tree Analysis

4.1 Fault Tree Analysis Methodology

The fault tree diagram provided examines the ”rough field” taxi mission failure through possible causes. The fault cell numbering correlates to the Fault Tree Event Description. The first part of the fault tree diagram provided presents the causes for an aircraft to fail the ”rough field” taxi mission. Our aircraft failed this mission due to it catching on an obstacle on the course. Potential causes for this specific performance failure are presented under the obstacle failure. The second, third, and fourth pages of the fault tree diagram outline all potential causes for a ”rough field” taxi mission failure due to the plane catching on a course obstacle. These causes are divided up into subsystems, and then further broken down to events for each subsystem to fail. The causes that are highlighted in green are the true root causes found through this analysis. The Fault Tree Event Description provides a definition of each failure event.

4.2 Detailed Fault Tree Diagram

In figure 4.1, the top level Fault Tree is shown. In figures 4.2, 4.3 and 4.4, the event ”Plane catches on ground obstacle” is developed further. This layout choice gives a better overview with respect to the small page format.

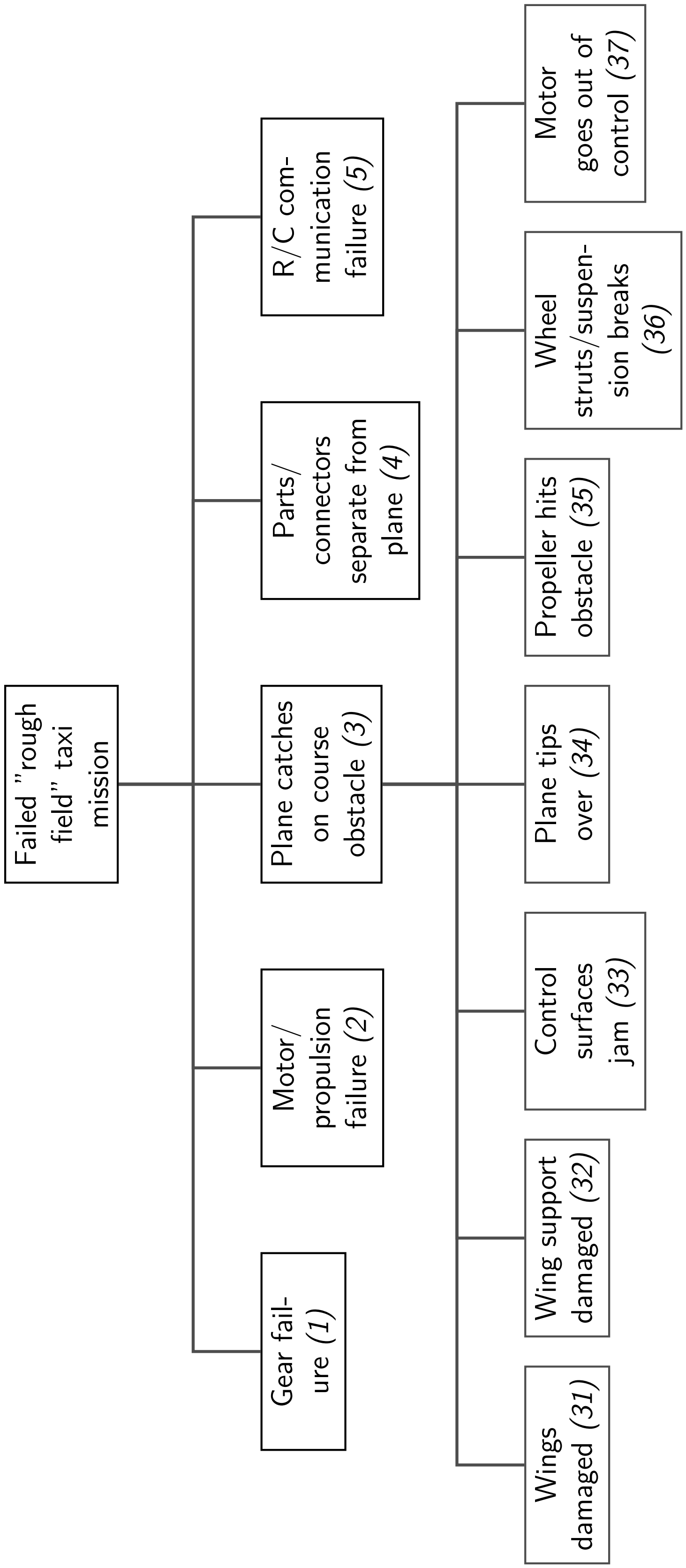
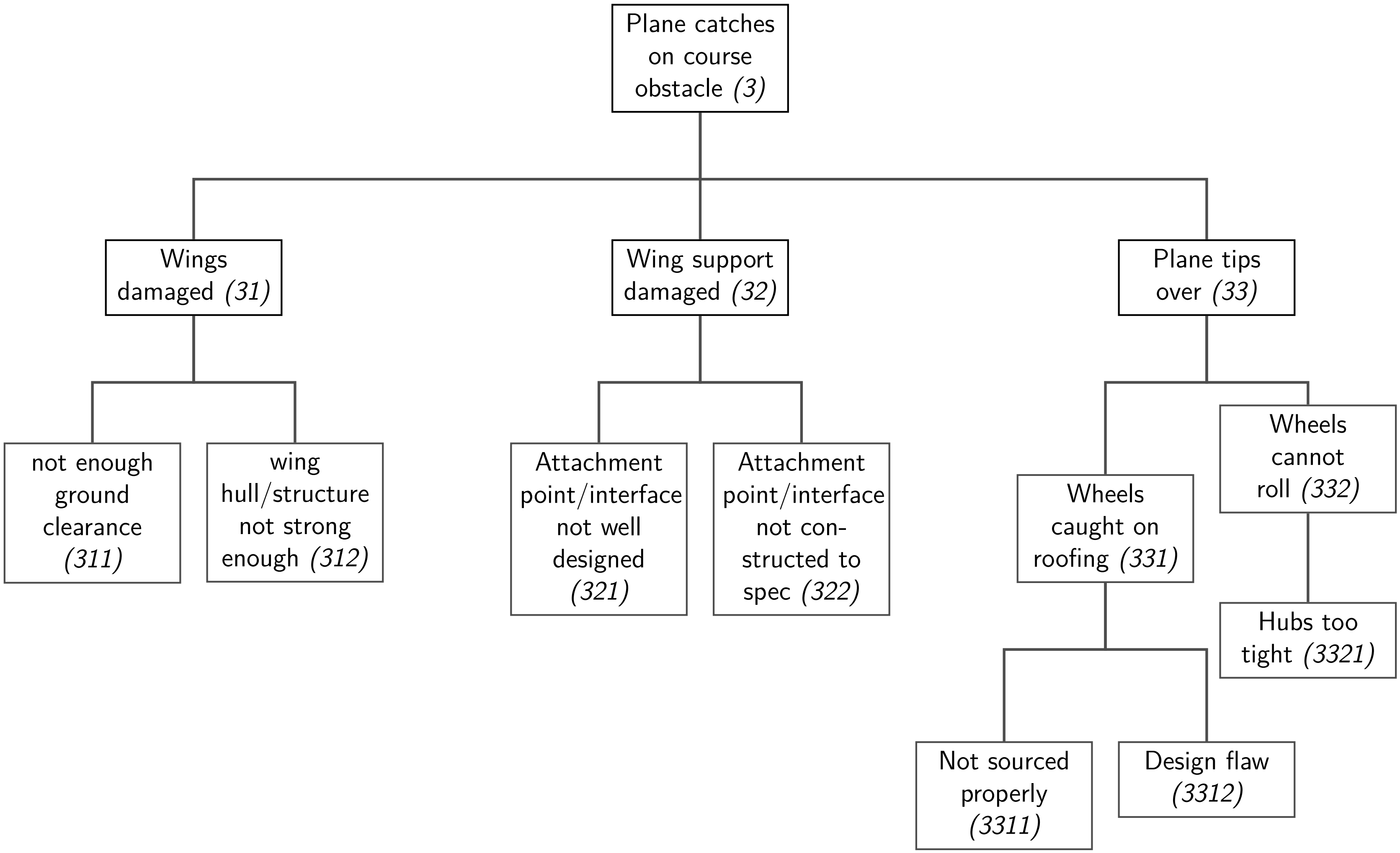


Fig. 4.1: Top level Fault Tree Diagram

Fig. 4.2: Deeper Levels for event "Plane catches on course obstacle"



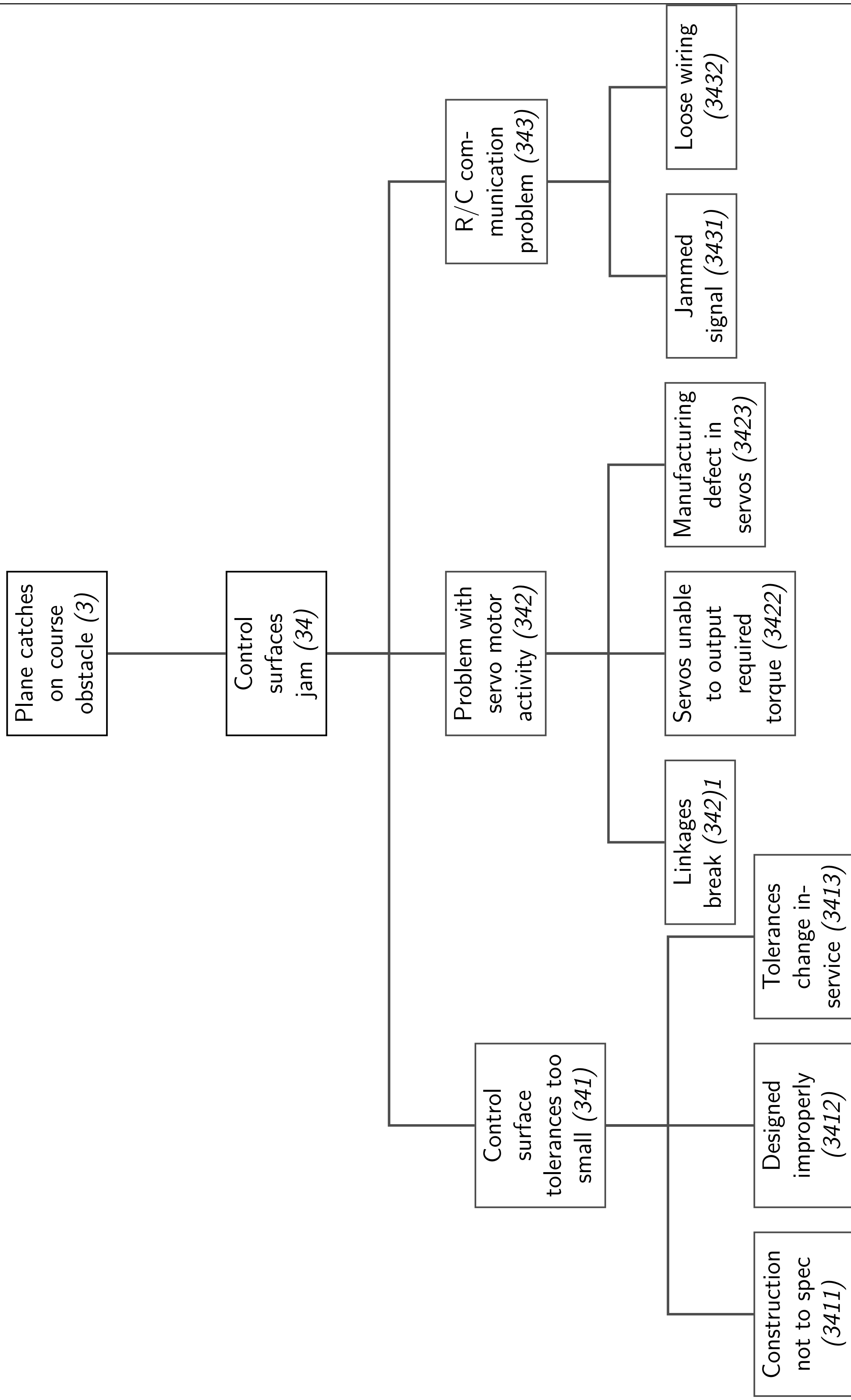


Fig. 4.3: Deeper Levels for event ”Plane catches on course obstacle” cont.

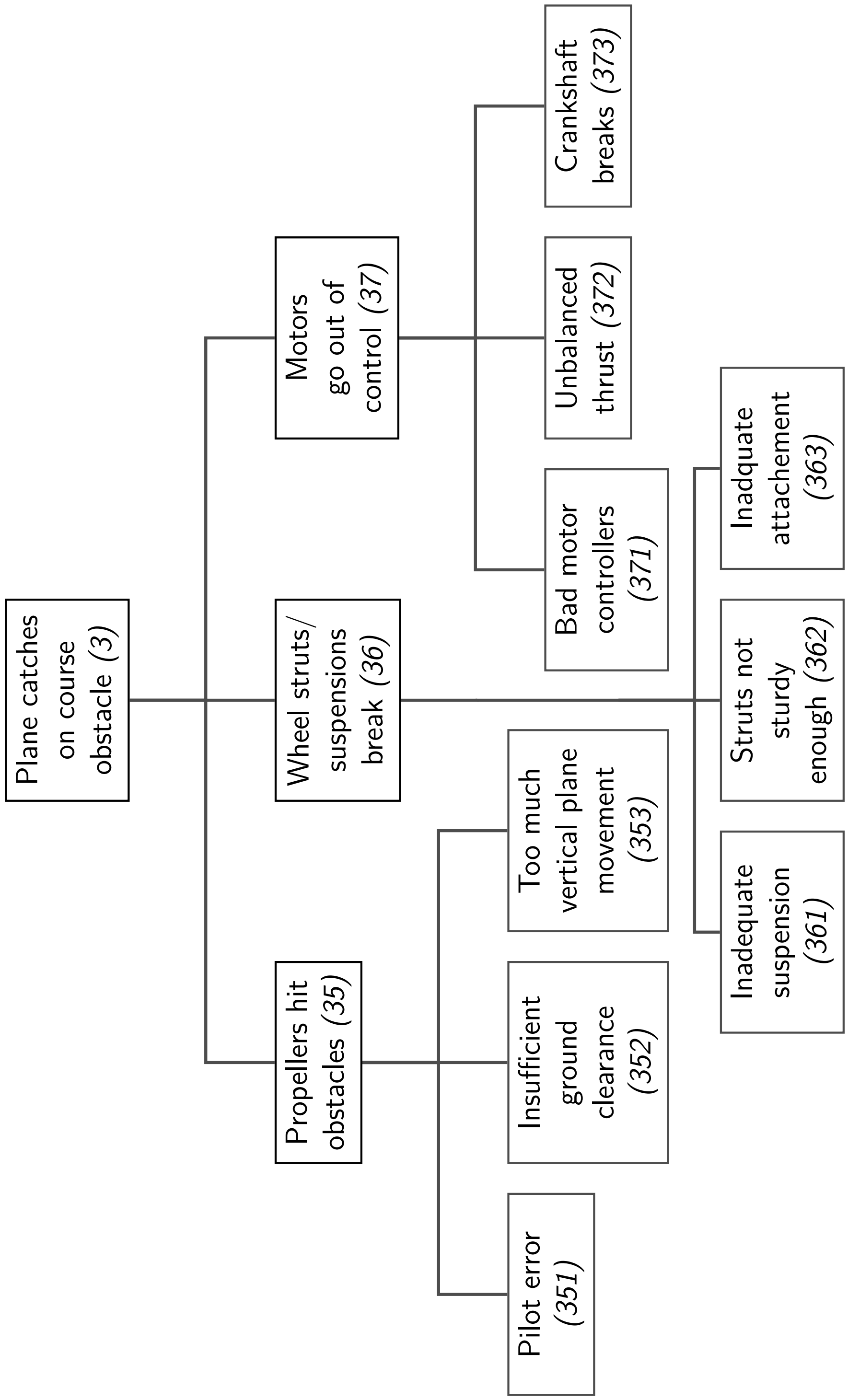


Fig. 4.4: Deeper Levels for event "Plane catches on course obstacle" cont. 2

4.3 Fault Tree Event Description

We concentrate on the major event ”Plane catches on course obstacle”, for which we provide several (root) causes. These causes will be discussed in the following section.

(31) **Wings damaged:** a damage to one of the major interfaces of the aircraft has severe effects on the current as well as on later missions.

- *(311)* **not enough ground clearance:** disregard of *Req. 2.2.III* is the cause of an insufficient design of the wing height
- *(312)* **wing hull/structure not strong enough:** a hard hit can pierce and thus destroy the wing hull and/or damage internal spars

(32) **Wing support damaged:** if the wings are not attached properly to the nacelle anymore, the aircraft might become uncontrollable

- *(321)* **Attachment point/interface not well designed:** a poor design which doesn't consider reliability and security is prone to failure
- *(322)* **Attachment point/interface not constructed to spec:** shoddy manufacturing (disregard of *Req 3.7.I*) leads to failure

(33) **Plane tips over:** if the plane does not stay upright during the taxi maneuver, further damage might be caused

- *(331)* **Wheels caught on roofing:** if the wheels fail to roll over the bumps of the roofing and get caught in the ”valley”, the plane tips over which might cause harm to miscellaneous components
  - *(3311)* **Not sourced properly:** components of bad quality might cause a failure root cause of failure
  - *(3312)* **Design flaw:** disregard of *Req. 2.3.II* renders the ”rough taxi” impossible
- *(332)* **Wheels cannot roll:** sliding over the roofing might destabilize the aircraft

motion

(3321) **Hubs too tight:** an over-tightening or incorrectly chosen allowance inhibits the wheels to turn <u>and thus is a root cause</u>

(34) **Control surfaces jam:** without properly operating control surfaces, the aircraft is not controllable anymore

(431) **Control surface tolerances too small:** undersized tolerances result in excessive friction of the control surfaces and the surrounding wing/tail structure

(4311) **Construction not to spec:** shoddy manufacturing of the control surface assemblies (disregard of *Req 3.7.I*) leads to failure

(4312) **Designed improperly:** a poor design which doesn't consider reliability and security is prone to failure

(4313) **tolerances change in-service:** improper integration of the control surfaces into the wing/tail cause lead to jamming

(432) **Problem with servo motor activity:** Malfunctioning servo motors lead to inoperability of the control surfaces

(4321) **Linkages break:** the torque is not anymore able to be translated into actual rotation movement

(4322) **Servos unable to output required torque:** the motors are unable to move the control surfaces adequately which severely impacts controllability

(4323) **Manufacturing defect in servos:** poor construction of the servos by the supplier leads to their failure

(433) **R/C communication problem:** inability of getting control signals to the aircraft renders it effectively uncontrollable

(4331) **Jammed signal:** a jammed signal transmits no or wrong information to the receiver

- *(4332)* **Loose wiring:** if the wiring fasteners fail to meet *Req 2.4.III*, they slacken and become disconnected

- *(35)* **Propeller hits obstacle:** a loss of the propeller robs the plane of its source of thrust
  - *(351)* **Pilot error:** too much thrust or wrongly operated control surfaces lead to a pitching moment that tips the plane over
  - *(352)* **Insufficient ground clearance:** if the ground clearance gets too low during dynamic taxiing, the propeller comes in contact with the roofing "hills"
  - *(353)* **Too much vertical plane movement:** disregard of *Req. 2.3.II* render the "rough taxi" impossible
- *(36)* **Wheel struts/suspension breaks:** without a functioning landing gear, the aircraft is not able to taxi, take off or land properly
  - *(361)* **Inadequate Suspension:** a bad choice of spring stiffness and damping renders the suspension ineffective
  - *(362)* **Struts not sturdy enough:** a poor design which doesn't consider reliability and security is prone to failure and thus a root cause
  - *(363)* **Inadequate attachment:** improper integration or shoddy manufacturing leads to failure of the landing gear
- *(37)* **Motor goes out of control:** a malfunctioning thrust source will lead to an incontrollable aircraft
  - *(371)* **Bad motor controllers:** a failure in the motor controllers entails the transmission of wrong control signal
  - *(372)* **Unbalanced thrust:** if one of the motors on a multi-engine aircraft fails, the thrust becomes asymmetric, which considerably deteriorates the controllability
  - *(373)* **Crankshaft breaks:** if the motor cannot transmit its torque anymore, the aircraft is without a thrust source

5 Fault Tree Analysis Summary

Analysis of the fault tree found that the true root causes of the failure were related to the wheel attachment. When conducting maintenance on the aircraft the wheel was tightened too tightly causing the wheel to rub against the landing gear strut. The true root causes are a design that allows the wheel to get too close to the landing gear structure and a lack of protocols in maintenance to ensure the wheels roll properly. Initially it was believed that the wheel design was poor and was locking up in tough conditions. This was found to not be true. Fortunately it was found to not be a major design failure. This discovery resulted in saving a significant amount of time on redesigning the landing gear.

6 Recommendation for Countermeasures

The root cause is not a design flaw; this failure was caused by a simple mistake made in maintaining the aircraft. Previous testing indicates that the wheels will function properly if they are not attached so tightly that they rub against the landing gear struts. Hence, the simplest and most effective apparent countermeasure is to make sure that the wheels are never tightened so hard. The maintenance documentation will be updated to reflect this warning. Additionally, all team members will be made aware of the cause of failure and the countermeasures enacted. This countermeasure can be enforced by performing a check before each flight to make sure that the wheels can roll freely. Additionally, as a second safeguard spacing washers were added to the landing gear axles to keep the wheels from getting in contact with the landing gear struts.

7 Lessons Learned