



**Australian Government**

**Australian Transport Safety Bureau**

# In-flight pitch disconnect involving ATR 72 aircraft VH-FVR

47 km WSW of Sydney Airport, New South Wales on 20 February 2014

**ATSB Transport Safety Report**

Aviation Occurrence Investigation

AO-2014-032

Second Interim Report – 5 May 2017

Released in accordance with section 25 of the *Transport Safety Investigation Act 2003*

#### **Publishing information**

**Published by:** Australian Transport Safety Bureau  
**Postal address:** PO Box 967, Civic Square ACT 2608  
**Office:** 62 Northbourne Avenue Canberra, Australian Capital Territory 2601  
**Telephone:** 1800 020 616, from overseas +61 2 6257 4150 (24 hours)  
Accident and incident notification: 1800 011 034 (24 hours)  
**Facsimile:** 02 6247 3117, from overseas +61 2 6247 3117  
**Email:** [atsbinfo@atsb.gov.au](mailto:atsbinfo@atsb.gov.au)  
**Internet:** [www.atsb.gov.au](http://www.atsb.gov.au)

© Commonwealth of Australia 2017



#### **Ownership of intellectual property rights in this publication**

Unless otherwise noted, copyright (and any other intellectual property rights, if any) in this publication is owned by the Commonwealth of Australia.

#### **Creative Commons licence**

With the exception of the Coat of Arms, ATSB logo, and photos and graphics in which a third party holds copyright, this publication is licensed under a Creative Commons Attribution 3.0 Australia licence.

Creative Commons Attribution 3.0 Australia Licence is a standard form license agreement that allows you to copy, distribute, transmit and adapt this publication provided that you attribute the work.

The ATSB's preference is that you attribute this publication (and any material sourced from it) using the following wording: *Source:* Australian Transport Safety Bureau

Copyright in material obtained from other agencies, private individuals or organisations, belongs to those agencies, individuals or organisations. Where you want to use their material you will need to contact them directly.

#### **Addendum**

Page	Change	Date

# Background

On 20 February 2014, a Virgin Australia Regional Airlines (VARA) ATR 72 aircraft, registered VH-FVR, operating on a scheduled passenger flight from Canberra, Australian Capital Territory to Sydney, New South Wales sustained a pitch disconnect while on descent into Sydney. The pitch disconnect occurred while the crew were attempting to prevent the airspeed from exceeding the maximum permitted airspeed ( $V_{MO}$ ). The aircraft was significantly damaged during the occurrence.

In accordance with the *Transport Safety Investigation Act 2003* (the Act), the ATSB initiated an investigation into the occurrence. On 15 June 2016 the ATSB released its first interim investigation report that contained the following safety issue:

- Inadvertent<sup>1</sup> application of opposing pitch control inputs by flight crew can activate the pitch uncoupling mechanism which, in certain high-energy situations, can result in catastrophic damage to the aircraft structure before crews are able to react.

In the interest of transport safety, this safety issue was brought to the attention of the aircraft manufacturer (ATR) and the wider aviation industry prior to completion of the investigation.

During the continued investigation of the occurrence, the ATSB has obtained an increased understanding of the factors behind this previously identified safety issue. This increased understanding has identified that there are transient elevator deflections during a pitch disconnect event that could lead to aerodynamic loads that could exceed the strength of the aircraft structure.

The ATSB also found that these transient elevator deflections were not identified, and therefore not considered in the engineering justification documents completed during the aircraft type's original certification process. The ATSB considers that the potential consequences are sufficiently important to release a further interim report prior to completion of the final investigation report.

This second interim report expands on information already provided in, and should be read in conjunction with, the interim report released on 15 June 2016 report and an update on the ATSB website on 10 June 2014.<sup>2</sup> It is released in accordance with section 25 of the Act and relates to the ongoing investigation of the occurrence.

Readers are cautioned that the factual information and analysis presented in this interim report pertains only to the safety issue discussed herein. The final report will contain information on many other facets of the investigation, including the operational, maintenance, training and regulatory aspects.

Readers are also cautioned that new evidence may become available as the investigation progresses that will enhance the ATSB's understanding of the occurrence. However, in order to ensure the veracity of the analysis of the evidence leading to the identified safety issue, the ATSB engaged the UK Air Accidents Investigation Branch (AAIB) to conduct a peer review. The AAIB conducted an analysis of the evidence relating to the safety issue and concluded that their findings were consistent with those provided by the ATSB.

---

<sup>1</sup> In the context of this safety issue, 'inadvertent' is taken to mean that the opposing pitch control inputs were unintended.

<sup>2</sup> [http://www.atsb.gov.au/publications/investigation\\_reports/2014/aaib/ao-2014-032.aspx](http://www.atsb.gov.au/publications/investigation_reports/2014/aaib/ao-2014-032.aspx).

# Context

## Pitch control system

### System flexibility

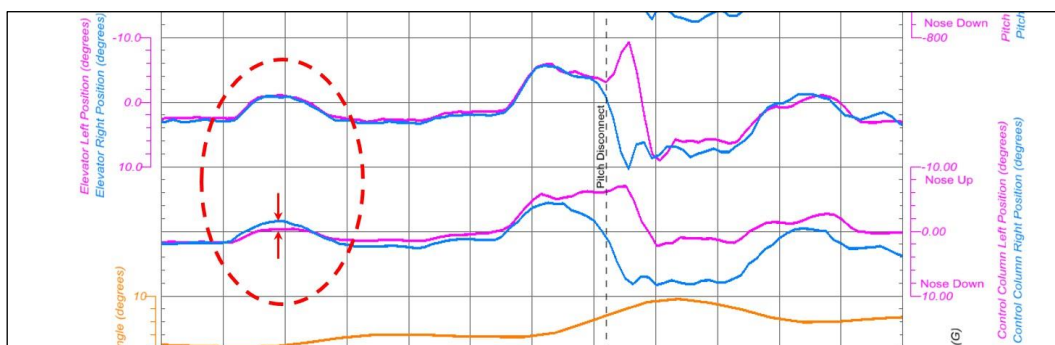
According to the aircraft documentation, the elevator deflection limits are 23° nose up to 13° nose down and the corresponding control column deflections are 11.25° nose up to 6.75° nose down.<sup>3</sup> Thus, the control column deflections are amplified by the pitch control system to result in elevator deflections about twice that of the control columns (a control column to elevator deflection ratio of about 1 to 2). That is, when the flight control column is deflected by 1°, the elevators deflect by 2°. However, it was noted that this control deflection ratio varied from this value during the flight. This was particularly noticeable in the immediate lead-up to the pitch disconnect event, where the ratio dropped below 1 to 1.

This change in the control deflection ratio was identified as being due to inherent flexibility in the control system. This flexibility means that the relationship between the elevator position and the control column position is modified by the force on the control column (the 'pitch axis effort') and the stiffness of the system. The result is, that the higher the force required to move the controls, the less that the elevators will move for a given control column movement.

The manufacturer reported that the cables in the pitch control system were primarily responsible for the flexibility. The cables extend from the control columns to the rear fuselage at the base of the vertical stabiliser. The remainder of the pitch control system running up the vertical stabiliser and back to the elevators is made up of push-pull rods, which are much stiffer.

In addition to the effect on the control column-elevator relationship, the control system flexibility also results in differences between the left and right control columns. This can be observed in the differences in the left and right control column positions before the pitch disconnect in the recorded data from the flight (Figure 1).

**Figure 1: Excerpt from the flight data recorder information around the time of the pitch disconnect. The circled area highlights a difference in the left and right control column positions (red arrows) during an input from the first officer on the right control column. Note, there is no corresponding difference between the position of the left and right elevators. For the complete image, refer to the previous interim report.**



Source: ATSB

This flexibility was also noted during the on-ground testing of the pitch disconnect system after the occurrence, where there was a noticeable difference between the left and right control column positions just before the pitch uncoupling mechanism activated (Figure 2).

<sup>3</sup> These deflections are based upon the travel limited by the elevator control stops (mechanical items that prevent further deflection). The control columns had additional stops that limited their travel from 13.25° nose up to 8.75° nose down.

**Figure 2: Still image from video of on-ground pitch disconnect testing carried out on VH-FVR following the occurrence. The right control column was held fully forward while the left control was pulled back. The image is just before the pitch uncoupling mechanism activated. Note the difference between the left and right control column positions. The left control column is about halfway through its full travel, while the right control column is at the forward limit.**



Source: ATSB

Although the control columns are physically located about 1 m apart, because the connection between the left and right systems is located between the elevators, the left and right control columns are mechanically separated from each other by approximately 60 m.

#### ***Calculation of the expected elevator deflections at the maximum operating speed***

As detailed in the analysis of this interim report, flexibility in the system results in a change to the elevator deflection following a pitch disconnect. In response to questions from the ATSB, the manufacturer calculated the expected differential in control column position and elevator deflection following a pitch disconnect at the maximum operating speed,  $V_{MO}$ . Their calculations were based upon the variable control column-to-elevator deflection ratio, due to the system flexibility, and the aerodynamic model for the aircraft. It was assumed that the control columns maintained their position following the pitch disconnect. Those calculations determined that the difference between the left and right:

- control column positions would be  $6.8^\circ$
- elevator deflections would be  $8.5^\circ$ <sup>4</sup>

<sup>4</sup> These calculations were carried out by the aircraft manufacturer before the ATSB had gained a full understanding of the transient elevator behaviour and briefed the manufacturer. Consequently, the calculations were based on a static balance of the forces between the control column input and the aerodynamic loads on the elevators. As a result, they represent steady-state elevator deflections following a pitch disconnect. That is, they are the deflections that, given time, the elevators would attain after the pitch channels disconnected from each other. Further discussion on this is contained in the safety analysis section of this report.

## Certification of the pitch disconnect system

During the certification of an aircraft type, the applicant (in this case the aircraft manufacturer) and the certifying authority<sup>5</sup> negotiate an agreed design standard and common interpretation of those standards. To obtain certification of the aircraft type, the applicant must satisfy the certifying authority that compliance has been demonstrated for all applicable sections of the agreed design standard.

### **Design standard**

The ATR 72 was designed and certified to the Joint Airworthiness Requirements Part 25 (JAR 25). The applicable change status of JAR 25 used for the certification was change 13. The ATSB identified that the following requirements are of particular relevance to this investigation.

#### **JAR 25.671 Control systems – General**

This section details a number of general requirements regarding the design of control systems. Of particular note is subsection (c) which states:

The aeroplane must be shown by analysis, test, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag and feel systems) within the normal flight envelope, without requiring exceptional piloting skill or strength. ...

The applicable failure case listed was case (3):

Any jam in a control position normally encountered during take-off, climb, cruise, normal turns, descent and landing unless the jam is shown to be extremely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such runaway and subsequent jamming is not extremely improbable.

#### **JAR 25.1309 Equipment, systems and installations**

This section applies to the safe functioning of equipment, systems and installations. The parts applicable to this investigation are:

- (a) The equipment, systems and installations whose functioning is required by the JAR and normal operating regulations must be designed to ensure that they perform their intended functions under any foreseeable operating conditions. (See ACJ Nos. 1 and 2 to JAR 25.1309.) ...
- (b) The aeroplane system and associated components, considered separately and in relation to other systems, must be designed so that (see ACJ Nos. 1 and 3 to JAR 25.1309) –
  - (1) The occurrence of any failure condition which would prevent the continued safe flight and landing of the aeroplane is extremely improbable, and
  - (2) The occurrence of any other failure condition which would reduce the capability of the aeroplane or the ability of the crew to cope adverse operating conditions is improbable.

...
- (d) Compliance with the requirements of subparagraph (b) of this paragraph must be shown by analysis, and where necessary, by appropriate ground flight or simulator tests. The analysis must consider (See ACJ No. 1 to JAR 25.1309) –
  - (1) Possible modes of failure, including malfunctions and damage from external sources.
  - (2) The probability of multiple failures and undetected failures.
  - (3) The resulting effects on the aeroplane and occupants, considering the stage of flight and operating conditions, and

---

<sup>5</sup> At the time that the ATR 72 was certified in 1992, the certifying authority was the *Direction générale de l'aviation civile* (the French National Aviation Authority). On 28 September 2003, the certifying authority changed to the European Aviation Safety Agency.

- (4) The crew warning cues, corrective action required, and the capacity of detecting faults.

To assist the designer in meeting the requirements of JAR 25.1309, additional guidance for 'acceptable means of compliance and interpretations' was provided in an associated ACJ (Advisory Circular - Joint). ACJ No. 1 to JAR 25.1309 was applicable as it provided the guidance material for assessment of the risks of failures and events on the safety of the aircraft.

The guidance stated that the objectives of JAR 25.1309 (a) to (d) were that,

Systems, considered separately and in relation to other systems, should be designed with the objective that there is an inverse relationship between the maximum acceptable probability of an occurrence and the severity of its Effect, such that a Catastrophe from all system causes is Extremely Remote.

The effects were categorised from minor through to catastrophic, where a:

- Minor Effect results in a slight reduction in safety margins such that the airworthiness is not significantly affected and any actions are well within the capability of the crew
- Major Effect results in a significant reduction in safety margins and there is a reduction in the ability of flight crew to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency. There may be injuries to occupants.
- Hazardous Effect results in a large reduction in safety margins. There may be physical distress to the flight crew and they cannot be relied upon to perform their tasks accurately or completely. Serious injury, or death, of a relatively small proportion of occupants may occur.
- Catastrophic Effect is one which results in the loss of the aeroplane and/or fatalities.

The associated probabilities for major, hazardous and catastrophic effects were defined as:

- Remote – unlikely to occur to each aeroplane during its total operational life but which may occur several times when considering the total operational life of a number of aeroplanes of the type. ( $10^{-5}$  to  $10^{-7}$  occurrences per flight hour<sup>6</sup>)
- Extremely Remote – unlikely to occur when considering the total operational life of all aeroplanes of the type, but nevertheless, has to be considered as being possible. ( $10^{-7}$  to  $10^{-9}$  occurrences per flight hour)
- Extremely Improbable – So Extremely Remote that it does not have to be considered as possible to occur. (less than  $10^{-9}$  occurrences per flight hour)

Although JAR 25.1309 and the associated ACJ are concerned primarily with failure conditions, the ACJ contains a section on operation without failure conditions which states:

Systems, considered separately and in relation to other systems, should be designed that, when they are operating within their specifications, it is Extremely Improbable that an Event will occur such as to cause a Catastrophe.

Where, an 'Event' was defined as an occurrence which has its origin distinct from the aeroplane.

### ***Flight control system safety assessment***

In showing compliance with the design standard during certification, in particular JAR 25.1309 and 25.671(c), the manufacturer completed a system safety assessment (SSA) for the flight control system. The ATSB was supplied with an extract of that SSA for items pertaining to the jamming of the flight control system and untimely operation of the pitch uncoupling mechanism.

The flight control SSA extract showed that the manufacturer's assessment included structural studies, simulation and flight test. Examination of the assessments made within the SSA extract found that the manufacturer had considered that if the system became jammed the pitch uncoupling mechanism (PUM) allowed the left and right channels to be separated, permitting

---

<sup>6</sup>  $10^{-5}$  occurrences per flight hour can also be thought of as 1 occurrence every 100,000 flight hours.



continued safe flight on one channel alone. There was also consideration of an untimely disconnect due to inadvertent activation, or mechanical failure of the PUM, that resulted in the separation of the two systems.

To demonstrate continued safe flight and landing, the manufacturer considered conditions that occur after the left and right channels had been separated. This included consideration of both the aircraft's handling qualities and the loads associated with manoeuvring the aircraft. They considered 6 jamming scenarios, including a jam during cruise at  $V_{MO}$ . For each of those scenarios, flight loads were computed for the expected manoeuvres, including those leading to load factors between -1g and 2.5g, and gust loads. There was no indication that the effects on the aircraft from any loads generated during activation of the PUM were considered.

The basic premise for a pitch disconnect at high airspeed, was that the aircraft could be safely slowed<sup>7</sup> to an airspeed below the limits that the manufacturer imposed for flight with a pitch disconnect. Those speed limitations were presented in the flight crew operating manual. The maximum of those aircraft limitations was 180 kts (70 knots below  $V_{MO}$ ) and there was no requirement to slow the aircraft to a speed below that limitation before disconnecting the controls.

Overall, the manufacturer assessed that the effect resulting from a jam or inadvertent operation of the PUM was 'major', when the correct procedure was applied. The probability was assessed as ranging from  $2.0 \times 10^{-7}$  to  $3.9 \times 10^{-7}$  occurrences per flight hour. Thus, the objective that major consequences occur at a rate no greater than 'remote' was shown for the cases studied. Associated with the SSA were the results from a flight test that was carried out to show compliance with JAR 25.671(c). The results also noted that the failure case was classified as major, but added that it was due to 'operational constraints'.

During the investigation, the aircraft manufacturer reassessed the likelihood of an untimely pitch disconnect due to inadvertent opposing dual control inputs. The reassessment was based upon the number of incidents reported to the manufacturer and the number of hours flown by the world-wide fleet of ATR aircraft. This reassessment determined that the occurrence rate was  $4.23 \times 10^{-7}$  occurrences per flight hour.

### ***Flight testing***

The flight test carried out during certification of the ATR 72 to demonstrate that the aircraft was 'capable of continued safe flight and landing without requiring exceptional piloting skill and strength following jamming of one pitch control channel' was done to demonstrate what the manufacturer considered was the most adverse case with regards to aircraft controllability. The case examined during the flight test involved manually holding the right control column such that the elevator was maintained at 11° nose up for a go-around and landing.

As a result of the testing, the manufacturer and certifying authority accepted that 'Approach and landing with one pitch channel jammed do not require exceptional skill or pilot strength when relevant procedure is applied'.

The flight test results provided to the ATSB included an 11 second section of data around the time that the flight crew intentionally activated the PUM and separated the pitch control channels in flight.

The flight test data showed that when the flight crew initiated the control inputs to separate the left and right pitch channels, the airspeed was at about 154 kt (96 kt below the aircraft's  $V_{MO}$ ) and the elevators were at about 4° nose up. As such, the pitch disconnect was carried out in preparation for the test, rather than being considered as part of the test to show compliance.

---

<sup>7</sup> That is, with acceptable handling qualities and without exceeding the aircraft limitations.



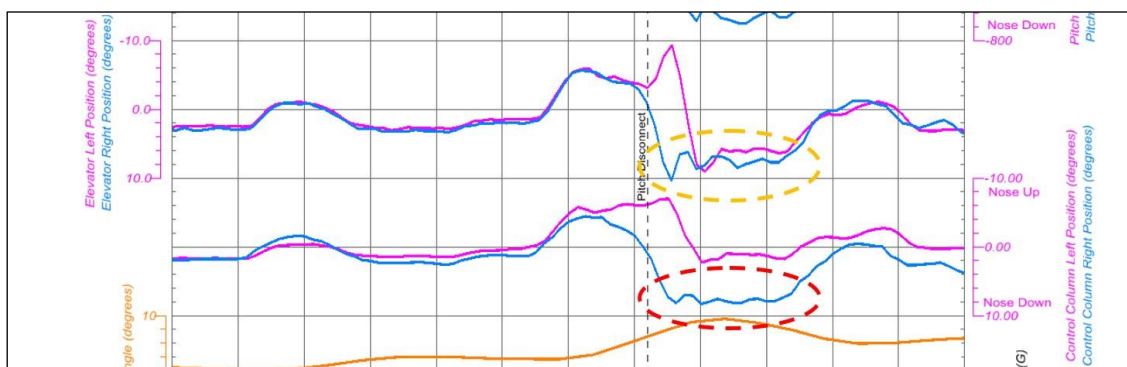
The flight test data also indicated that the pitch disconnect was achieved by the right seat occupant holding the control column in a fixed position while the test pilot in the left seat pulled back on the control column with sufficient force to activate the PUM.

An ATSB review of the recorded flight test data identified that the:

- maximum recorded pitch axis efforts were 62 daN and 56 daN on the left and right pitch channels, respectively
- maximum difference between the elevator positions during the test was 34° (left elevator at -23° and right elevator at 11°)<sup>8</sup>
- left control column moved a further 5° nose up following activation of the PUM while the recorded pitch axis effort dropped from 62 to 20 daN.
- elevator movement following activation of the PUM was characteristic of a transient underdamped oscillatory behaviour (refer to appendix A).

A similar transient oscillatory characteristic, was identified in the FDR data during the pitch disconnect occurrence on VH-FVR (Figure 3).

**Figure 3: Excerpt from the FDR data from VH-FVR during the pitch disconnect event. The underdamped oscillatory characteristic response of the elevator movement following pitch disconnect is circled in yellow.**



Source: ATSB

## Design load

The manufacturer advised that, having considered a number of load cases, the maximum ultimate load<sup>9</sup> condition for unsymmetrical elevator deflection was the loads generated by the following conditions, plus an additional 10 per cent margin:

- 154 kt airspeed
- elevator nose down (as a result of jammed 8° the stick pusher jamming at full extension)
- one the other elevator at full nose up position, leading to a difference of 33° between both elevators<sup>10</sup>

<sup>8</sup> The sign convention used in the chart (that is, which direction is considered positive) was such that positive deflections indicated nose-down inputs and negative deflections indicated nose-up inputs.

<sup>9</sup> According to the Joint Aviation Requirements (JAR) 25.301, the ultimate load is the limit load multiplied by a prescribed factor of safety. JAR 25.305 requires that the aircraft structure must be able to support the ultimate load without failure for at least 3 seconds.

<sup>10</sup> Given that the FCOM lists the maximum nose up elevator deflection as 23°, the difference equates to 31°, not 33°.

The manufacturer further advised that the ultimate load was also equivalent to the following conditions, without any margin:

- the above condition at 161 kt
- differential elevator deflections of 36° (full opposing deflections) at 154 kt
- differential elevator deflection of 15.6° at 250 kt ( $V_{MO}$ ).

# Safety analysis and finding

## Introduction

It has previously been identified that the pitch disconnect event on VH-FVR was a result of simultaneous uncoordinated control inputs that led to opposing loads on the controls. It was also identified that such inputs, although not part of normal procedures, could be hazardous to the operation of the aircraft. In the interim report released on 15 June 2016, the ATSB indicated that the existing procedural risk controls alone may not be sufficient to prevent this type of occurrence and as such, the ATSB were:

...investigating whether the design of the pitch control and associated warning systems increases the likelihood of potentially catastrophic damage occurring when flight crew inadvertently make opposing control inputs.

As a result of that further investigation, the ATSB has obtained an enhanced understanding of the dynamics of the pitch control system during a pitch disconnect event and identified an additional safety factor that relates to the potential loads generated during such an event.

The design of the pitch control system is such that the crew is required to apply a load to the control column in order to separate the left and right pitch control systems in the event of a jam. The ATSB has identified that this has three effects on the controls during a pitch disconnect event,

- rebalancing of the loads in the system following activation of the pitch uncoupling mechanism (PUM)
- dynamic transient elevator deflections in the short period after activation of the PUM
- unavoidable movement of the control column(s) following activation of the PUM.

The first two of these effects are a consequence of the flexibility within the control system and the PUM being located between the elevators.

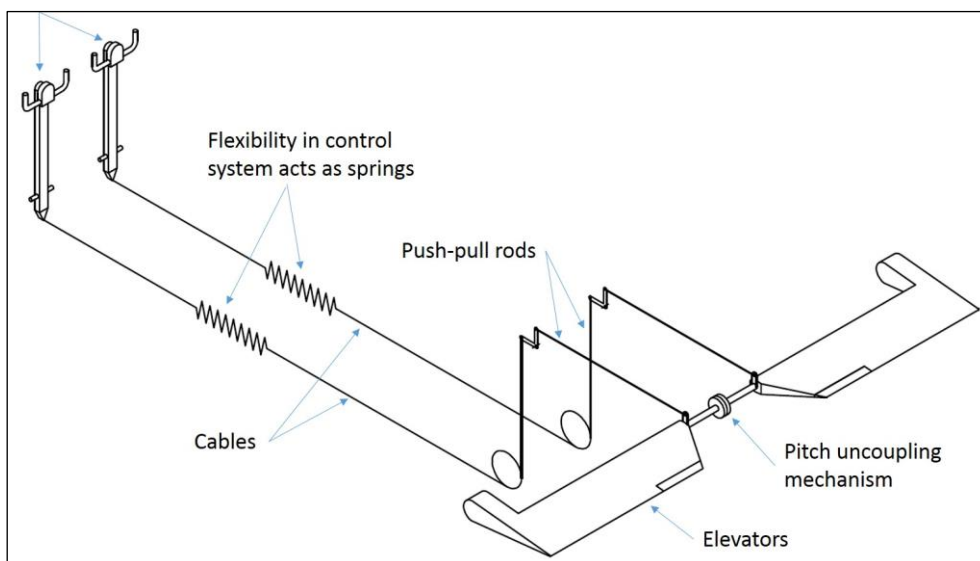
Each of these effects may contribute to elevator deflections greater than the aircraft manufacturer considered during the design and certification of the aircraft.

## Effect of the flexibility in the pitch control system

### ***Simplified model of the pitch control system***

The flexibility in the pitch control system acts like a spring which stores potential energy within the system when a tension load is applied. Although the pitch control system consists of a relatively complex arrangement of push-pull rods, bellcranks, pulleys and cables connecting the control columns to the elevators, the system can be represented as the simplified system shown in Figure 4. Although not detailed in the figure, the design of the system is such that a tension is generated within the control cables regardless of whether the controls are pushed or pulled. The manufacturer advised that the flexibility is primarily within the control cables, so for the purposes of the simplification the flexibility of the entire system is represented as a spring within the control cables.

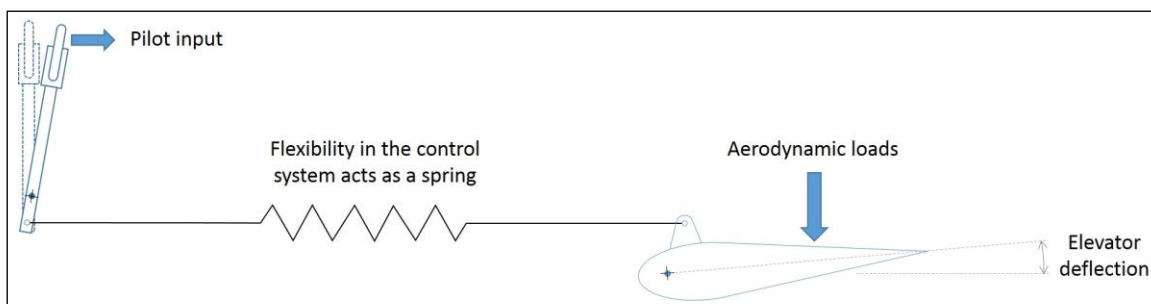
**Figure 4: Simplified model of the pitch control system with the flexibility in each channel being represented as a spring in the control cables**



Source: ATSB

In considering the behaviour of this system, this representation can be further simplified to one channel of the pitch control system (Figure 5). In this simplified representation, when the control column is pulled back an upward deflection of the elevator will result. This elevator deflection generates an aerodynamic load that acts in the direction opposite the deflection. The opposing forces between the control column and the aerodynamic load on the elevator will result in a tension in the system. Because the system acts like a spring, it will stretch under this tension.

**Figure 5: Simplified model of one pitch control system channel showing the generalised balance of loads in the system**



Source: ATSB

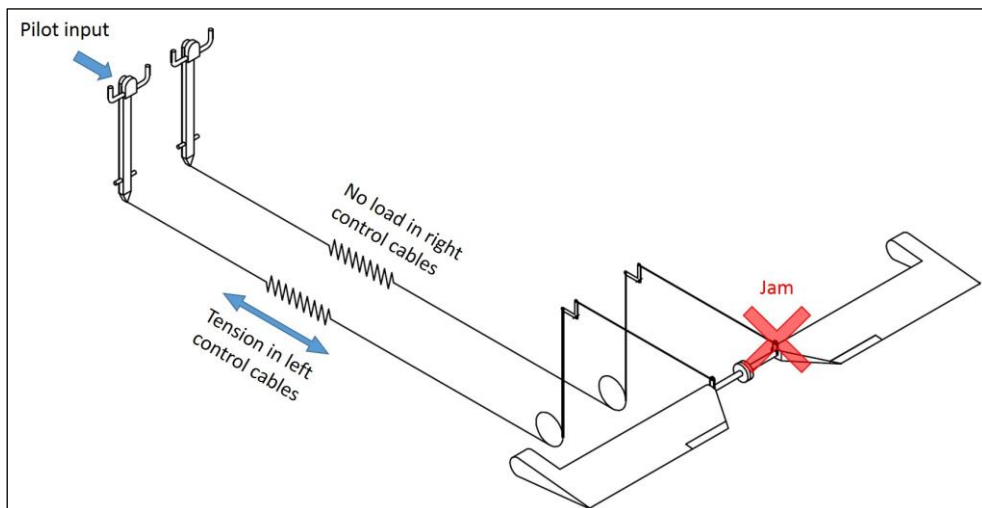
### ***Control deflections from rebalancing of the loads after a pitch disconnect***

In normal operation, when there is only one pilot on the controls and there are no jams, the load on the control column is balanced by the resulting aerodynamic load on both elevators. The torque between the elevators required to activate the PUM has been designed to be high enough that the torque generated by one elevator is not sufficient to activate the PUM during standard manoeuvres throughout the flight envelope. However, if there is a jam in the system, or there are opposing dual control inputs, the load applied to the control column is also counteracted by the jam, or the load from the other control column input. In the case of a jam, the response of the system will differ depending upon where the jam is located.

If the jam is located at, or close to, the elevators, forces applied to the control columns (control input) will result in a tension in the system, but there will be effectively no movement of the elevators while the pitch uncoupling mechanism (PUM) is connected (Figure 6). When the PUM

activates, the jammed elevator will remain in the same position, but the elevator of the unjammed side is free to move.

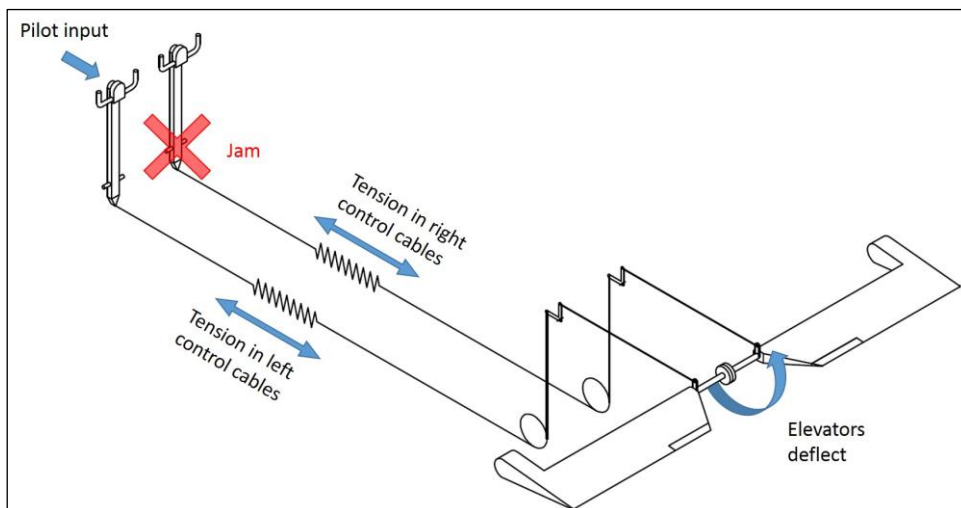
**Figure 6: Simplified model of the pitch control system with a jam at, or close to, the right elevator.**



Source: ATSB

If the jam is at, or close to, a control column (Figure 7), input to the free control column can result in some elevator deflection because of the flexibility in the system. This deflection will result in an aerodynamic load in a direction opposite to the deflection, but it will also generate a tension in the control system between the elevators and the jammed control column. After the activation of the PUM, the non-jammed control channel is free to move. However, unlike the case where the jam is at the elevator, the elevator of the jammed channel still has some movement as a result of the system flexibility.

**Figure 7: Simplified model of the pitch control system with a jam at control column**



Source: ATSB

In the case of no jam, but opposing dual control inputs, the system will act in a manner similar to a jam at a control column; however, both control channels have full movement following PUM activation. The following discussion does not consider the effect of the unavoidable movement of the control columns following activation of the PUM. This effect will be examined separately.

When the PUM activates, the position of the elevators will be changed without further movement of the control columns because of the rebalancing of the loads and tensions in the system. This is described in detail below.

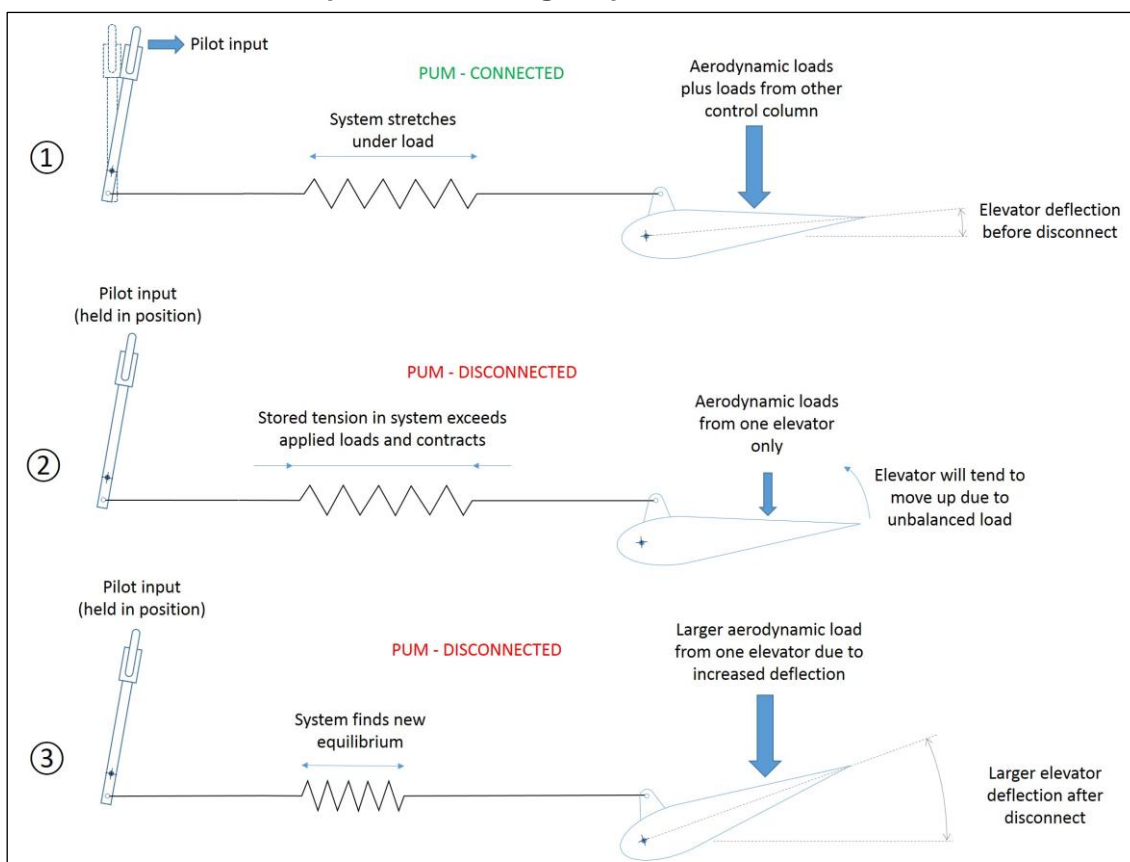
Figure 8 represents how one pitch control channel changes in response to a pitch disconnect. The case examined represents the case of a jam at one control column, or opposing dual control inputs. The behaviour presented assumes that the control column has been moved to the position at which the PUM is activated, but does not move following the pitch disconnect. Only one pitch channel is shown; however, due to the balance in the system, the other channel will behave in a similar manner, but in the opposite direction.

The instant before a pitch disconnect occurs ①, the PUM has not been activated and the left and right elevators are connected. The control load input through one system is balanced by the aerodynamic load from both the left and right elevators and the tension generated in the other pitch channel (Figure 7). Because of the inherent flexibility, the system between the control column and elevator has been stretched.

At the instant that the PUM activates ②, the left and right systems separate and each channel is only reacting the aerodynamic load from one elevator. The loads in the system are no longer balanced, so the tension in the control system will act to reduce the stretch in the system and the elevator will tend to move up.

The contraction of the system will increase the deflection of the elevator until the aerodynamic load on the elevator balances the load on the control column ③. The new deflection will be larger than the position just before the pitch disconnect.

**Figure 8: Behaviour of the pitch control system during a pitch disconnect shown just before the pitch disconnect ①, the instant of the pitch disconnect ②, and at a time after the pitch disconnect when the loads have balanced ③. Note, this assumes that the control column is held in position following the pitch disconnect.**



Source: ATSB

In the case where the jam occurs at, or close to, the elevator, the elevator will not move until the PUM activates, but tension will build up in the control system and it will stretch. When the PUM

activates, the control system on the free elevator channel will contract and the elevator will move to a new position where the loads are balanced.

This is the case that the manufacturer assessed during the investigation in response to ATSB questions. The results of the calculations carried out by the manufacturer suggest that the effect of the elevator movement following a pitch disconnect would not be a hazard because the expected difference in elevator deflections at the maximum operating speed is  $8.5^\circ$ , which is less than the ultimate load case of  $15.6^\circ$  at the same speed. However, this is only one effect that results in elevator deflections following a pitch disconnect event. This effect also provides the driving force that results in a dynamic transient behaviour.

### ***Dynamic transient elevator deflections***

Because the pitch control system is made up of components that contain mass, it is not possible for the elevators to move from one position to another instantaneously. There will be a period of time during which the elevator is transitioning from the initial position to the final position. The behaviour of the system during this time period is a complex combination of the system's mass distribution, stiffness and damping;<sup>11</sup> however, there are certain characteristic responses that can be observed in such transient dynamic systems.

As previously described, the ATR 72 pitch control system has an inherent flexibility that results in it acting like a spring. In addition, the aerodynamic loads on the elevators act in the opposite direction to the deflection and increase in magnitude with an increase in the deflection, thus also acting like a spring.<sup>12</sup>

By design, friction in the flight control system is minimised, hence there may be little damping from system friction. However, the aerodynamics of rapidly deflecting an elevator will provide damping to the system.<sup>13</sup>

Review of the certification flight test data and the data recorded on the occurrence flight indicated that the system had an oscillatory response consistent with an underdamped system.<sup>14</sup> An important characteristic of an underdamped system is that there is an overshooting of the steady-state, before settling to the final value. Thus, when the elevators move to a new position following activation of the PUM, it is likely that they will overshoot the steady-state deflection, generating greater aerodynamic loads on the horizontal stabiliser than the steady-state situation would suggest. The degree of overshoot has not been determined as part of this investigation and would require significant engineering analysis to quantify the effect over the complete operating envelope.

## **Unavoidable control column movement following activation of the pitch uncoupling mechanism**

As previously stated, to activate the PUM and separate the left and right pitch control channels, a significant load needs to be applied to the control column(s). The analysis presented in this report has also shown that when the PUM activates, there is a sudden change in the force balance within the system that results in movement of the elevators without any additional control column movement. However, this sudden imbalance will also result in unavoidable movement of the control column.

When the PUM activates and the load through the pitch channel decreases to only the aerodynamic load from one elevator, the excess load applied to the control column is no longer balanced and as a result will accelerate in the direction of the applied force. This movement will

---

<sup>11</sup> Damping is a force that opposes motion. In many situations, the damping force is proportional to the rate of movement (velocity).

<sup>12</sup> Those aerodynamic forces also increase with airspeed.

<sup>13</sup> Damping forces such as these can be felt when rapidly waving a handheld fan side-to-side.

<sup>14</sup> Refer to Appendix A for information on the characteristic responses of simple dynamic systems.



increase the tendency for the elevator to move from the position it was in before the pitch disconnect, further increasing the aerodynamic loads on the horizontal stabiliser.

The amount of control column movement after activation of the PUM may be affected by a number of factors, including the flight crew's expectation for a pitch disconnect and the airspeed.

An important factor in the amount of control movement is the expectation that the flight crew has of an impending pitch disconnect. The more that a response to a predictable stimulus is anticipated, the faster the reaction will be to that stimulus.<sup>15</sup> Hence, if the flight crew are not expecting a pitch disconnect, the time to recognise the change in the control column force and consequently movement may be greater than if it is expected.

During the certification flight testing, the aircraft was being operated by professional test personnel with the intention of activating the PUM to separate the left and right pitch control channels. Thus, they were in a situation where they had an expectation of a pitch disconnect, yet the left control column was moved about 5° after the pitch disconnect.

However, during the VH-FVR pitch disconnect occurrence, the flight crew were attempting to prevent an exceedance of the maximum operating speed. Therefore, it is very unlikely that they were expecting a pitch disconnect and, as such, it is reasonable to expect greater movement of the control column than had they been anticipating it.

Another factor that may affect the amount of control column movement following a pitch disconnect is the aerodynamic loads on the elevators. At higher airspeeds, the aerodynamic load per degree of elevator deflection is greater. Consequently, the force resisting the control column movement due to the aerodynamic load on the elevators is greater. Therefore, the expected elevator and corresponding control column movements, would be expected to be less at higher airspeeds. However, at higher airspeeds, the resulting aerodynamic load on the horizontal stabiliser may not be smaller as a result of the reduced elevator deflection. The investigation has not determined the relative effects of these and quantifying this effect would require significant engineering analysis.

## Manufacturer's considerations during certification

The certification documents provided to the ATSB indicated that the aerodynamic loads on the horizontal stabiliser generated by the elevator deflections from a pitch disconnect had not been considered during the design and certification of the pitch control system in the ATR 72. However, the recorded data from the occurrence flight and a certification flight test show that there are elevator deflections during a pitch disconnect event. The only indication that the aircraft manufacturer had considered the effect of elevator deflections during a pitch disconnect event was in answer to questions posed by the ATSB; however, those calculations did not consider all the factors that affect the elevator deflections. There was no indication in the certification data that the manufacturer had identified the transient effects in the elevator system that result from a pitch disconnect and, as such, they were not considered.

The ATSB's investigation identified that the dynamic transient elevator deflections and unavoidable control column movement will result in greater elevator deflections than those calculated by the manufacturer. Those deflections increase the aerodynamic loads generated by the horizontal stabiliser, and in turn the potential to overstress the structure.

During the intentional pitch disconnect done in preparation for the certification flight testing, the ultimate load was not exceeded. However, the elevator deflections encountered were only about

---

<sup>15</sup> Stefanics, G., Hangya, B., Hernadi, I., Winkler, I., Lakatos, P., & Ulbert, I. (2010). Phase entrainment of human delta oscillations can mediate the effects of expectation on reaction speed. *Journal of Neuroscience*. 2010 October 13; 30(41): 13578-13585. Doi:10.1523/JNEUROSCI.0703-10.2010.

2° less than the ultimate load case. According to the manufacturer, a speed increase of only about 7 knots was required to reach the ultimate load with those elevator deflections.

During the VH-FVR occurrence, the resulting elevator deflections were sufficient to exceed the ultimate load by about 47 per cent. This indicates that there is potentially a speed below the maximum operating speed at which the ultimate load case can be exceeded during a pitch disconnect event.

Because there has been no detailed engineering to assess the transient elevator deflections and unavoidable control movements, there is no assurance that the aircraft has sufficient strength to sustain the aerodynamic loads generated by a pitch disconnect event at all speeds within the approved operating envelope.

While it is accepted that dual control inputs are not a normal piloting practice, it is considered by the ATSB to be a foreseeable error. Indeed this appears to have been considered by the manufacturer during certification; however, the resulting effect was categorised as 'major'. Given the understanding of the effect of a pitch disconnect at that time, this categorisation was considered reasonable. However, an improved understanding of the transient elevator deflections that occur during a pitch disconnect, may conclude that a 'major' categorisation may no longer adequately estimate the hazard to the aircraft. For any categorisation more severe than major, neither the predicted nor the reassessed occurrence rate meet the accepted standard.

# Findings

On 15 June 2016 the ATSB released an interim investigation report that contained the following safety issue:

- **Inadvertent application of opposing pitch control inputs by flight crew can activate the pitch uncoupling mechanism which, in certain high-energy situations, can result in catastrophic damage to the aircraft structure before crews are able to react. [Safety issue]**

While this issue focussed on the potential for catastrophic damage during inadvertent activation of the pitch uncoupling mechanism (PUM) from opposing dual control inputs, additional investigation has identified that the inherent behaviour of the elevator control system design could potentially result in an ultimate load exceedance from the deliberate activation of the PUM to overcome a jam. Based on the results of this additional investigation, the ATSB makes the following finding:

- **The aircraft manufacturer did not account for the transient elevator deflections that occur as a result of the system flexibility and control column input during a pitch disconnect event at all speeds within the flight envelope. As such, there is no assurance that the aircraft has sufficient strength to withstand the loads resulting from a pitch disconnect. [Safety issue]**

# Safety issue and actions

The safety issues identified during this investigation are listed in the Findings section of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

In this case, the ATSB has assessed that the risk posed by the safety issue is of sufficient magnitude to warrant the release of an additional interim report. This action provides the earliest opportunity for the relevant organisation to initiate proactive safety action, rather than wait for the final investigation report.

The safety actions presented in this section are only those that are directly related to the safety issue identified in this report. A number of other safety actions have been taken in response to the safety issue identified in the interim report released on 15 June 2016. The initial public version of these safety issues and actions are repeated separately on the ATSB website to facilitate monitoring by interested parties. Where relevant the safety issues and actions will be updated on the ATSB website as information comes to hand.

## Consideration of transient elevator deflections from a pitch disconnect

### ***Safety issue description:***

The aircraft manufacturer did not account for the transient elevator deflections that occur as a result of the system flexibility and control column input during a pitch disconnect event at all speeds within the flight envelope. As such, there is no assurance that the aircraft has sufficient strength to withstand the loads resulting from a pitch disconnect.

### ***Application of the safety issue to both ATR 42 and 72 models***

Although the flight control system in the ATR 72 has been assessed in this report, the ATR 72 is a longer version of the ATR 42 and the design of the flight control system is common to both models. The different length of the control runs is likely to have an effect on the flexibility, but the uncertainty that results from the lack of detailed engineering assessment means that the safety issue also applies to the ATR 42 model.

### ***Initial safety action taken by the ATSB***

On 11 November 2016, the ATSB notified ATR of the concerns identified in this report. The ATSB also notified the Australian operator of the aircraft, the Civil Aviation Safety Authority and the Federal Department of Infrastructure and Regional Development.

The issue was further discussed with ATR at meetings on 18 November 2016 and 1 December 2016. The European Aviation Safety Agency was also present during those meetings.

### ***Proactive safety action taken by ATR***

On 1 December 2016, in response to the identified safety issue, ATR advised the ATSB that they intended to:

- perform a risk assessment to determine the short term risks associated with continued operation

- conduct a detailed engineering analysis of the transient elevator loads during a pitch disconnect.

### ***Short term risk assessment***

On 15 December 2016, ATR provided the ATSB with the results of their assessment of the short term risks of continued operation awaiting the complete engineering work associated with the issue. Their assessment concluded that:

ATR considers that continued safe operation is ensured by considering

- In the jamming situation, the ultimate loads cannot be exceeded through the control column input (excessive effort and mechanical stops). At high speed, the differential elevator deflection has margin to accommodate the transient load.
- The probability of a repeat occurrence of the MSN1058 [VH-FVR] event defeating all the barriers inherent in the design and standard operating procedures.
- The quantitative analysis results showing no immediate action is required.

### ***Detailed engineering analysis of transient elevator deflections***

On 11 April 2017, ATR provided the ATSB with an update on the detailed engineering analysis of the transient elevator loads. The briefing included an overview of the analysis methodology and preliminary results.

The analysis being conducted is based upon an analytical model supported by both ground and flight testing. The analytical model represents the ATR pitch control system and has system component masses and stiffness represented as group blocks. This includes a block representing the pitch uncoupling mechanism (PUM), which was modelled to represent the behaviour of the PUM before, during and after activation.

ATR has compared the model to the behaviour of the system recorded during ground test and has identified a favourable correlation. The results of the model showed that, following activation of the PUM on the ground, without aerodynamic loads, the flight control system responded in an underdamped oscillatory manner.

For analysis of the inflight situation, ATR has used the aerodynamic model that was developed during certification. Preliminary results for the jamming scenarios was provided. Those results showed that the inflight system response is also that of an underdamped oscillatory system. It also indicates that the magnitude of the system response is dependent upon the pilot input to the control column, and how quickly the flight crew respond to PUM activation. The system has margin for jams at the elevator. ATR are continuing the analysis of jams at the control column.

ATR are continuing with the detailed analysis. Further work includes:

- Flight testing to determine a suitably realistic pilot response to activation of the PUM
- Verification of the analytical model with data recorded during the flight tests
- Modelling of the dual input case
- Modelling of other cases required by the European Aviation Safety Agency.

### ***ATSB comment/action in response***

The ATSB acknowledges the efforts of ATR to resolve the safety issue. The ATSB also notes that, while the short-term risk assessment does not account for the transient elevator deflections associated with a pitch disconnect, until the results of the detailed engineering analysis are available it is not possible to accurately quantify the transient elevator loads. Consequently, it is not possible to fully determine the magnitude of the risk associated with continued operation of ATR42/72 aircraft until the engineering analysis is complete.

Noting the above, the ATSB's retains a level of ongoing concern as to whether the aircraft has sufficient strength to withstand the loads resulting from a pitch disconnect. Consequently, while

the ATSB accepts that the current level of safety action partially addresses the safety issue; the ATSB makes the following safety recommendations.

Number:	AO-2014-032-SI-02
Issue owner:	ATR
Operation affected:	Aviation: Air transport
Who it affects:	All operators of ATR 42 and 72 aircraft

***ATSB safety recommendation to ATR***

Action number: AO-2014-032-SR-014

Action status: Released

The ATSB recommends that ATR complete the assessment of transient elevator deflections associated with a pitch disconnect as soon as possible to determine whether the aircraft can safely withstand the loads resulting from a pitch disconnect within the entire operational envelope. In the event that the analysis identifies that the aircraft does not have sufficient strength, it is further recommended that ATR take immediate action to ensure the ongoing safe operation of ATR42/72 aircraft.

Number:	AO-2014-032-SI-02
Issue owner:	European Aviation Safety Agency
Operation affected:	Aviation: Air transport
Who it affects:	All operators of ATR 42 and 72 aircraft

***ATSB safety recommendation to the European Aviation Safety Agency***

Action number: AO-2014-032-SR-015

Action status: Released

The ATSB recommends that EASA monitor and review ATR's engineering assessment of transient elevator deflections associated with a pitch disconnect to determine whether the aircraft can safely withstand the loads resulting from a pitch disconnect within the entire operational envelope. In the event that the analysis identifies that the aircraft does not have sufficient strength, it is further recommended that EASA take immediate action to ensure the ongoing safe operation of ATR42/72 aircraft.

Number:	AO-2014-032-SI-02
Issue owner:	Civil Aviation Safety Authority
Operation affected:	Aviation: Air transport
Who it affects:	All operators of ATR 42 and 72 aircraft

***ATSB safety recommendation to the Civil Aviation Safety Authority***

Action number: AO-2014-032-SR-016

Action status: Released

The ATSB recommends that CASA review ATR's engineering assessment of transient elevator deflections associated with a pitch disconnect, to determine whether the aircraft can safely withstand the loads resulting from a pitch disconnect within the entire operational envelope. In the event that the analysis identifies that the aircraft does not have sufficient strength, it is further recommended that CASA take immediate action to ensure the ongoing safe operation of Australian-registered ATR42/72 aircraft.

***Current status of the safety issue***

Issue status: Monitor

Justification: The ATSB acknowledges the efforts of ATR with regard to the detailed engineering analysis of the transient elevator deflections. The preliminary results have shown that the system responds in an underdamped oscillatory manner, resulting in elevator deflections greater than those identified by the static analysis previously carried out by ATR. The ATSB is encouraged by the level of detail into which ATR have developed the analysis and will continue to monitor their progress. Until such time that the analysis has satisfactorily shown that the aircraft has sufficient strength to withstand the loads resulting from a pitch disconnect, the identified safety issue will remain open.

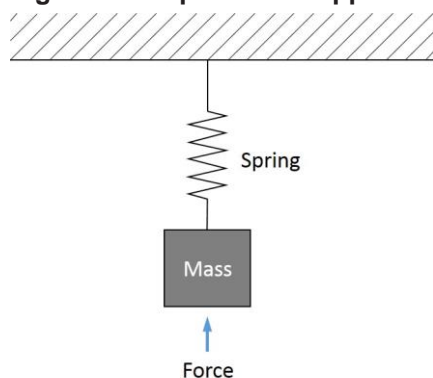


## Appendix A – Transient response of a simple dynamic system

This appendix provides a brief overview of the characteristic transient responses of a simple dynamic system. Although the pitch control system in the ATR 72 is more complex than the example presented, the characteristic responses of the systems are qualitatively applicable to more complex systems.

A simple mechanical system consisting of the mass supported by a spring is shown below (Figure 9). If no force applied, the position that the mass is at will be considered the normal resting position. However, if a force is applied to the mass, the position of the mass will change, albeit not instantaneously. There will also be a period of time that the mass will be in motion. The motion of the mass during this time is referred to as the transient response of the system.

**Figure 9: Simple mass supported from a spring that is acted upon by a force**



The final condition of the mass after the transient movement has ceased is referred to as the 'steady-state' condition.

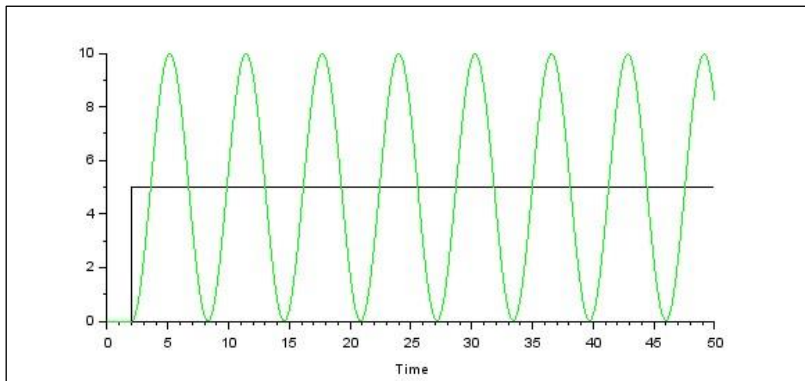
The manner in which the system responds before reaching the steady-state condition depends on the input force, the mass, the spring stiffness and the damping in the system. Damping is a force that resists motion and is typically proportional to the speed. Damping can be either specially designed as part of the system, such as a shock absorber in a car's suspension, or may be from characteristics inherent in the system, such as friction or aerodynamic drag.

A common way of examining the system response is to determine how the system will respond to specific simple inputs. A typical input used in the study of dynamic systems is the step input.<sup>16</sup> The relative magnitude of the damping in the system results in characteristic transient responses to the step input.

If there is no damping, the mass will endlessly oscillate without ever settling to a steady-state, as shown in Figure 10. The magnitude and frequency of the oscillation are functions of the mass and spring stiffness.

<sup>16</sup> An input that changes from one value to another over a zero time interval.

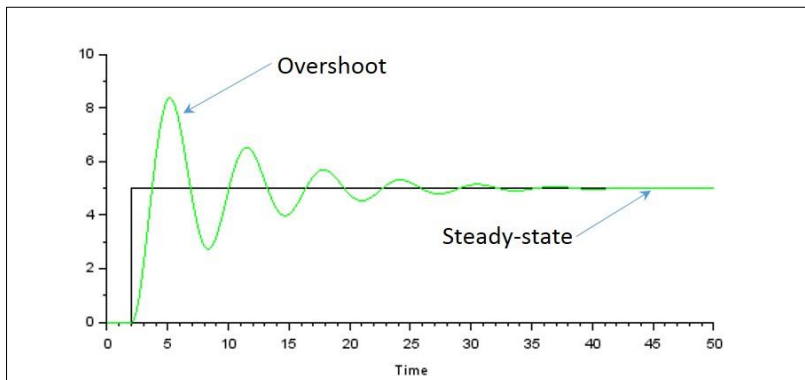
**Figure 10: Response of a simple mass-spring system (green trace) to a step input (black trace) with no damping. Note that the system will continue to oscillate without settling to a steady-state.**



Source: ATSB

When some damping is added to the system, the oscillation reduces over time and the mass will eventually settle to a new steady-state position as shown in Figure 11. This characteristic response is referred to as an under-damped system. A key feature of this response is that the system will initially overshoot the steady-state value.

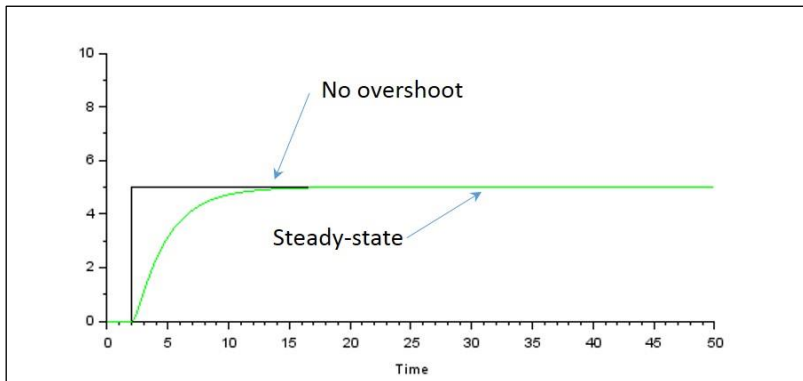
**Figure 11: Characteristic response of an underdamped simple mass-spring system (green trace) to a step input (black trace). Note that the system will oscillate, but the magnitude of the oscillation will decrease over time until the system reaches a steady state value.**



Source: ATSB

Increasing the damping will reduce the amount of overshoot and oscillation before reaching the steady-state; however, the initial response will be slower. If the damping is sufficiently large, there will be a point where there is no oscillation within the system. The minimum amount of damping that results in no overshoot is called the critical damping. Further damping will display a similar response, but will slow the response and increase the time that it takes to reach the steady-state position. The characteristic response of a critically, or overdamped system is shown in Figure 12.

**Figure 12: Characteristic response of an overdamped simple mass-spring system (green trace) to a step input (black trace). Note that there is no oscillation and the system does not overshoot the steady-state value.**



Source: ATSB

# Australian Transport Safety Bureau

The ATSB is an independent Commonwealth Government statutory agency. The ATSB is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to operations involving the travelling public.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

## Purpose of safety investigations

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

## Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.