Australian Government
Australian Transport Safety Bureau

Operation of the PZL-Mielec M18 Turbine Dromader at take-off weights above 4,200 kg

Investigation

ATSB Transport Safety Report
Aviation Safety Issue Investigation
AI-2011-150
Final – 9 April 2013

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ATSB TRANSPORT SAFETY REPORT

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SAFETY SUMMARY

What happened

In the period 2006 to 2012, the Australian Transport Safety Bureau (ATSB) investigated three fatal accidents involving PZL-Mielec M18 Dromader aircraft. All three investigations identified actual and potential safety issues regarding the operation of M18 Dromader aircraft at take-off weights above 4,200 kg. Although the aircraft were all permitted to operate at increased weights, the ATSB sought an understanding of any common factors across the investigations, and whether there were any implications for the continued safe operation of the type at those increased weights. As a result, the ATSB initiated a safety issues investigation in November 2011 to examine those factors and identify any potential safety issues.

What the ATSB found

The investigation identified several safety issues indirectly arising from the operation of M18 aircraft at increased weights. Though some of these issues were minor in isolation, collectively the increase in risk was more significant and the investigation illustrated the need for careful consideration of potential risks when expanding an aircraft's role and/or capability.

The investigation established issues regarding the:

- practicality of a 15° bank angle limitation that is imposed at increased weights, which would probably affect or preclude some agricultural operations,
- potential for pilots and operators to apply incorrect operating limitations for flights at some weights under a relevant Supplemental Type Certificate (STC),
- method used to apply service life adjustments required at higher weights,
- risk of aircraft incorporating the STC not being configured to the same standard as the flight test aircraft, and
- risk to operators if they do not recalibrate a hopper sight level gauge when changing the hopper size and/or shape.

What has been done as a result

The owner and developer of the STC reported that they were in the process of amending it and were developing a proposal for Civil Aviation Safety Authority consideration and approval. This proposal would address the maximum bank angle limitation and required aircraft modifications, as well as clarify the applicability of the flight manual limitations and airframe service life adjustment method.

Safety message

The investigation highlights some of the risks involved in increasing an aircraft's operating weight. The importance of pilots and operators understanding and applying any operating limitations that might accompany an operational enhancement is also highlighted.

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Acknowledgements
Figure 1: Courtesy of Mr Roger Syratt

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau 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 fare-paying passenger operations.

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 safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

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 appropriate, or to raise general awareness of important safety information in the industry. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing safety factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Risk level: the ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

FACTUAL INFORMATION

Background information

Reasons for the investigation

In the period 2006 to 2012, the Australian Transport Safety Bureau (ATSB) investigated three fatal accidents involving PZL-Mielec M18 Dromader aircraft:[1]

- Investigation 200600851, in which an M18A that was conducting firefighting operations on 16 February 2006 and departed from controlled flight during a turn at low altitude, most probably the result of an inadvertent aerodynamic stall.
- Investigation AO-2008-084, where a wingtip separated from an M18A during agricultural spraying on 29 December 2008, resulting in a loss of control.
- Investigation AO-2011-082, in which an M18A that was conducting spraying operations on 19 July 2011 departed from controlled flight during a turn at low altitude for reasons that could not be determined.

Those investigations identified three significant safety issues[2] and some other safety concerns with respect to the operation of M18 Dromader aircraft at take-off weights above the aircraft's Normal-category maximum take-off weight (MTOW). Although the aircraft were all permitted to operate at these increased weights, the ATSB sought an understanding of any common factors across the investigations, and whether there were any implications for the continued safe operation of the type at those increased weights. As a result, the ATSB initiated a safety issues investigation in November 2011 to examine those factors and identify any potential safety issues.

Previously-identified safety issues

Although they were not shown to have contributed to the particular accidents, the previous accident investigations identified a number safety issues relating to the operation of the increased weights.

Investigation AO-2008-084 into the second M18 accident identified two significant safety issues in relation to the operation and maintenance of the Turbine Dromader at increased weights as follows:

- Operation of the M-18A in accordance with Civil Aviation Safety Authority exemptions[3] EX56/07 and EX09/07 at weights in excess of the basic aircraft flight manual maximum take-off weight (MTOW), and up to the MTOW listed on the Type Certificate Data Sheet, may not provide the

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1 The investigation reports are available at http://www.atsb.gov.au/

2 In each case, those safety issues were not found to have contributed to the accident in question.

3 Exemptions EX56/07 and EX09/07, which were valid from 2007 to 2009, exempted a pilot from compliance with the aircraft's published or otherwise approved MTOW.

same level of safety intended by the manufacturer when including that weight on the Type Certificate.

- A number of operators of the PZL M18 Dromader aircraft had not applied the appropriate service life factors to the aircraft's time in service for operations conducted with take-off weights greater than 4,700 kg, as required by the aircraft's service documentation. Hence the operators could not be assured that their aircraft were within their safe service life.

Investigation AO-2011-082, the investigation into the third accident in the series examined by this safety issues investigation, identified the following significant safety issue in relation to the operation of the Turbine Dromader at increased weights:

- The aircraft's centre of gravity varied significantly with hopper weight and could exceed the forward and aft limits at different times during a flight.

The respective investigation reports, available on the ATSB website at http://www.atsb.gov.au, provide more information including safety actions that were undertaken or planned to address those safety issues.

Since the release of those reports, the Civil Aviation Safety Authority (CASA) advised it intended 'to undertake a sampling program to establish if Dromader aircraft operators have applied the advice regarding operations at increased maximum take-off weight as well as the advice provided on potential inflight Centre of Gravity shift.'

Aircraft type certification and modifications

A Type Certificate (TC) is a document issued by an airworthiness authority to indicate design approval of a particular aircraft type. Aircraft with a foreign TC may be accepted in Australia if the TC was issued by the national airworthiness authority (NAA) in at least one recognised country, or by the European Aviation Safety Agency (EASA) - as was the case for the M18.

A TC includes a Type Certificate Data Sheet (TCDS), which contains a formal description of the aircraft. This includes detailed specifications of the type design, and the information required for type certification.

Minor modifications to an aircraft must be approved by a suitably qualified engineer with the appropriate delegation from the NAA. Instructions for those modifications are typically contained in a document called an Engineering Order (EO).

For major changes, a Supplemental Type Certificate (STC) may be required. An STC may be designed for a particular aircraft, or designed to be applied to multiple aircraft of the same make and model. The STC may include references to the applicable EO(s) for instructions on the physical changes to the aircraft and typically also requires changes to the aircraft's operating and/or maintenance documentation. These changes can affect the aircraft flight manual (AFM) or maintenance manual.

As is the case of a foreign TC, a foreign STC may be accepted in Australia if it was issued by EASA or by an NAA of a recognised country.

Aircraft operational limitations

A TCDS includes mandatory operational limitations, including maximum aircraft weights. In addition, the AFM publishes mandated aircraft limitations for application by pilots.

An AFM can include supplements that promulgate additional instructions, conditions, limitations, and information. Inclusion of AFM supplements in the parent manual might be optional, for example to allow for different types of operation. Alternately a supplement can be mandatory, for example if required by the incorporation of an STC. Any limitations introduced by supplements are mandatory. Some AFM limitations may only apply for certain types of operation, such as firefighting or agricultural aerial application.

CASA may publish exemptions to any regulation. This can include regulations relating to the requirement for pilots to adhere to certain published limitations.

Aircraft information

The PZL-Mielec M18 Dromader is a low-wing agricultural aircraft with seating for a pilot and, in some variants, one passenger (Figure 1). The aircraft type was originally fitted with a nine-cylinder radial piston engine and 2,500 L hopper, with a maximum hopper load weight of 1,500 kg. There were three main aircraft variants, the M18, M18A, and M18B.[4] The engine was rated as producing up to 967 horsepower for continuous operation, depending on the variant.

A US Federal Aviation Administration (FAA) STC allowed the aircraft to be fitted with a Honeywell TPE331 turboprop engine. Sometimes referred to as 'Turbine Dromaders', these aircraft included a constant-speed propeller that was driven via a reduction gearbox. The turbine engine was rated as producing up to 1,000 shaft horsepower for continuous operation, depending on the variant.

An aircraft with a TPE331 engine could be further modified under an Australian EO to enlarge the hopper to a capacity of 3,000 L.[5] On its own, the EO did not change the maximum weight that could be carried, but offered the benefit of being able to carry more low-density material (such as granules) in the enlarged hopper. It also did not explicitly require a recalibration of the cockpit hopper level sight gauge that was used by pilots to see the quantity of material present in the hopper.

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[4] Throughout this report, 'M18' is used generically to refer to any of the three main variants except where otherwise stated. Two-seat trainer versions of the M18A and M18B were not considered in this investigation.

[5] It was reported that the hopper could not be completely filled in practice. The actual useable capacity varied between aircraft. As an indication, it was reported that a typical maximum load was about 2,600 L.

Figure 1: File photograph of an M18A Turbine Dromader, registration VH-FOZ

Operations at increased weights

Weights permitted by the M18 TCDS

The M18 TCDS mandated a MTOW of:

- 4,200 kg for the 'Normal-category' version (applicable to the M18, M18A, and M18B variants)
- 4,700 kg for the 'overload' version (M18 and M18A)
- 5,300 kg for the 'fire-fighting overload' version (M18 and M18A)
- 5,300 kg for the 'Restricted Category'[6] version (M18B).

Three AFM supplements (PZL supplements No. 1, 16, and 17) were available from the aircraft manufacturer in support of operations at the increased weights. Although their inclusion in an AFM was not mandatory, if an operator intended to carry out operations at those increased weights, the relevant supplement needed to be included in the AFM. Once incorporated in the AFM, the additional conditions, limitations and information in the relevant supplement had effect during any operations above 4,200 kg.

Supplement No.17 was only applicable to the M18B variant and included a maximum hopper load of 2,200kg.

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[6] A restricted category aircraft was certified for designated special purpose operations as set out in Civil Aviation Safety Regulation 21.025(2). These included agricultural operations, such as spraying and livestock control, and firefighting.

Weight increase permitted by the incorporation of Australian STC SVA521

The Australian STC SVA521 permitted M18 and M18A aircraft operations at weights up to 6,600 kg. This STC required incorporation of an AFM supplement and a Maintenance Manual Supplement in the respective manuals. PZL Supplements No. 1, 16 and 17 were not required to be incorporated in an aircraft's AFM as a prerequisite for operations under STC SVA521.

CASA advised ATSB that:

> ...[the risk of] this increase in MTOW was compensated for:
>
> - by reducing the allowable normal load factor and applying a Service Life Reduction Factor to account for structural effects [and]
> - by a flight test program that confirmed the aircraft's performance and handling were acceptable at the higher weights, and by applying appropriate flight limitations within which the aircraft had acceptable performance and handling.

Weight increase permitted by CASA exemption

Prior to 2011, several CASA exemptions had effect relating to the operation of restricted or agricultural category aircraft at weights in excess of the AFM maximum take-off weight. In general, they exempted pilots from different parts of the Civil Aviation Regulations or Civil Aviation Safety Regulations either directly or indirectly pertaining to the requirement to adhere to take-off weight limitations. This was predicated on the complying aircraft having a jettison system installed that allowed pilots to reduce aircraft weight by dumping the hopper load if and when necessary.

In November 2011, as part of investigation AO-2008-084, the ATSB advised CASA of the potential for a different interpretation of the exemptions than intended by CASA. It was identified that, in certain circumstances, this could result in an aircraft being flown outside the relevant weight-dependent limits.

In February 2012, CASA revoked those exemptions and introduced exemption EX01/12, which clarified the requirements for operations in excess of the AFM maximum take-off weight.

Operational limitations at increased weights

Some of the operational limitations imposed by the aircraft's TCDS, AFM and the relevant AFM supplements are listed in Table 1.

Table 1: Operational limitations

Source	MTOW (kg)	Never exceed speed, V_{NE}[7] (KIAS)[8]	Maximum bank angle in the turn	Maximum manoeuvring flight load factor (g)[9]
Type Certificate Data Sheet	4,200 (normal category)	151	None specified	-1.4 / +3.4
	4,700[A] (overload category)	124	None specified	-1.2 / +3.0
	5,300 (firefighting overload)	124	None specified	-1.1 / +2.8
Basic AFM[B]	4,200	121	60º	-1.4 / +3.4
PZL AFM Supplement No. 1	4,700	121	60º	-1.2 / +3.0
PZL AFM Supplement No. 16	5,300	121	15+5°[D]	-1.1 / +2.8
PZL AFM Supplement No. 17[C]	5,300	124	30°	-1.1 / +2.8
Australian STC SVA 521 AFM Supplement	6,600	135	15°	-0.9 / +2.25 (at 6,600 kg) -1.1 / +2.8 (at 5,300 kg)

[A] Applicable to the M18 and M18A only.

[B] Incorporating a supplement for the TPE331 engine installation.

[C] Applicable to the M18B only.

[D] The aircraft manufacturer advised that the turn bank angle was 15° and that +5° was the 'maximum margin of safety'.

The basic AFM mandated an additional airspeed limitation of 104 KIAS with 'dusting spraying or atomizing equipment installed'. That airspeed limitation was not revoked by STC SVA521 and so had effect in operations carried out in accordance with the supplement.

The aircraft manufacturer advised that the bank angle limitation in PZL AFM Supplement No. 16 was a result of flight testing. CASA advised that, during the development and approval of STC SVA521, the STC owner/developer was unable

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7 V_{NE} is the maximum speed permitted under any circumstances.

8 Knots indicated airspeed.

9 'g' is the nominal value for acceleration. In flight, g-load values represent the combined effects of flight manoeuvring loads and turbulence. This can be a positive or negative value.

to discover the reason for that limitation so it elected to include the limitation for the STC with CASA approval.

Operation type

PZL AFM Supplement No. 16 stated that 'the aircraft with the weight of 11,700 Lbs (5,300 kg) is not permitted for agricultural missions.'

None of the other supplements prohibited any operation type (that is, agricultural or firefighting).

Applicability of limitations

The limitations imposed by PZL AFM Supplements No. 1, 16, and 17 applied to all weight ranges up to the maximum specified in each supplement, with the exception of the bank angle limit in PZL AFM Supplement No. 17. This limit was only applicable in the 4,200 to 5,300 kg weight range.

Australian AFM supplement 207/403/FMS stated that the limitations in that supplement were 'applicable to all M18 [and] M18A aircraft operations at weights above 5,300 kg up to a maximum of 6,600 kg'.

A summary of the limitations that were applicable to the various categories of increased-weight operations is outlined in Table 2.

Table 2: Applicability of operational limitations

<table>
<tr><th>Weight range</th><th>Basic AFM</th><th>PZL AFM Supp. No. 1</th><th>PZL AFM Supp. No. 16</th><th>PZL AFM Supp. No. 17</th><th>Australian AFM Supp. 207/403/FMS</th></tr>
<tr><td>4,200 kg and below</td><td>✓</td><td rowspan="2">If incorporated</td><td rowspan="2">If incorporated and for firefighting only</td><td rowspan="2">If incorporated and for M18B only</td><td rowspan="2">✘</td></tr>
<tr><td>4,200 kg to 4,700 kg</td><td rowspan="3">✘</td></tr>
<tr><td>4,700 kg to 5,300 kg</td><td rowspan="2">✘</td></tr>
<tr><td>5,300 kg to 6,600 kg</td><td>✘</td><td>✘</td><td>✓</td></tr>
</table>

Longitudinal instability

PZL AFM Supplement No. 16 Section 4 *Normal Procedures* included the following observation:

> 4.10. Level Flight
>
> The aircraft shows dynamic longitudinal instability with free control stick /after about 20 seconds and two vibration cycles, the aircraft shows tendency to reaching the stall speed or exceeding the allowable maximum flight speed/.

There was no parallel notification of a longitudinal instability issue in any of the other AFM supplements. The certification flight test report in support of STC SVA521 (see *STC flight tests* on page 9) stated that the test aircraft's longitudinal stability was 'adequate at all times'.

Aircraft maintenance in support of operations at increased weights

The AFM and maintenance manual supplements for operations at weights above 4,700 kg included the requirement to adjust the aircraft's service life by a factor dependent on the aircraft's take-off weight. In this respect, PZL AFM Supplement No. 16 stated that:[10]

> The [aircraft's] service life is determined for the airplane takeoff weight of 10340 Lbs (4700 kg). The increase in the takeoff weight up to 11700 Lbs (5300 kg) results in higher fatigue wear and service life drop by 1.35 times. The recorded flown hours of the aircraft with weight ranged from 10340 Lbs (4700 kg) to 11700 Lbs (5300 kg) shall be multiplied by 1.35 coefficient and the obtained result used for counting the service life.

In addition, Australian AFM supplement 207/403/FMS stated that:

> The service life of the M18 is determined at a MTOW of 4700kg. The increase in the take-off weight up to 5300kg, and then again to 6600kg results in higher 1g stress loads and therefore a reduction in the service life of the airframe. The recorded flight hours must be multiplied by the factors specified in Section 2.4 of the approved STC Maintenance Manual Supplement, 207/403/MMS, in order to calculate the remaining service life of the airframe.

and the MMS (original emphasis) that:

> The actual recorded flight time is to be adjusted by the applicable factor provided in Table 1, or Figure 1 [partly reproduced as Table 3 below] in order to determine the "corrected" service life, (TIS), of the aircraft when operated in accordance with the CASA Approved Restricted Category STC No. SVA521, "Operations with MTOW up to 6600kg". It is the corrected service life which is to be used as the basis for scheduling and completing all of the required aircraft maintenance and inspection tasks.

Table 3: Service life reduction factor quick reference table for STC SVA521

Initial Take-off Weight (kg)	Applicable Service Life Reduction Factor
6600	2.50
6400	2.30
5900	1.85
5300	1.35
4700 and below	1.0

[10] PZL AFM Supplement No. 17 included an almost identical statement.

An engineering report on the fatigue aspects produced in support of STC SVA521, stated that:

> All specified maintenance or inspection intervals specified … need not be reduced provided that the recorded flight hours are adjusted in accordance with Section 2.5 of this report in order to account for operation of the M18 aircraft in the overweight configuration.

Applying the service life reduction to the aircraft's time in service in accordance with the weight-dependent factor would in effect shorten some service intervals. The aircraft manufacturer advised that this shortening of service intervals was an intentional consequence of the adjustment of recorded flight hours required by AFM Supplement No. 16. The owner/developer of STC SVA521 reported that the intended method of applying the hours was to keep separate logs of the actual flying hours and an adjusted, 'airframe fatigue life', which was used as the basis for determining total life and fatigue-related maintenance. Since the factoring was applied, this method also reduced the effective service intervals for airframe fatigue-related maintenance.

At least one maintenance organisation applied the time in service factoring in an alternative manner. The method used was to subtract the additional flight time derived by the application of the weight-dependent factor from the total permissible airframe life. The maintenance organisation reported that this method was used to prevent maintenance from being conducted more frequently than necessary on items that were not affected by the aircraft's increased weight, such as the aircraft's engine and flight instruments. The extent to which other organisations may also have performed the service life adjustments this way was not determined.

A comparison of the two means of applying the aircraft weight-dependent factor to a hypothetical aircraft's maintenance schedule and airframe life following a flight of 1.2 hours duration and a take-off weight of 6,400 kg is at Appendix A.

STC flight tests

A series of flight tests was conducted by the developer of STC SVA521 to show regulatory compliance of the modification. These included tests of the aircraft's trim, controllability, static and dynamic stability, roll rate, stall characteristics, and vibration and buffeting tests at aircraft weights up to 6,600 kg.

The aircraft that was used in those flight tests was reported to have been fitted with vortex generators[11] that were claimed by their manufacturer to provide for a 7% reduction in an aircraft's stall speed, as well as improved aileron authority and reduced turning time. Elevators that had been modified to match those fitted to the M18B were also reported to have been fitted.

STC SVA521 and the associated documentation included a list of required equipment and modifications, such as the turbine engine and increased capacity hopper. It did not require the installation of vortex generators or M18B standard elevators. CASA advised the ATSB that its intent for the approval of the STC 'was

[11] Small vanes that are designed to create aerodynamic vortices. On some aircraft, including the M18, they may be attached to the upper surface of the wing to delay separation of the airflow over the wing at low speeds. This improves lift and controllability.

always that aircraft fitted with STC SVA521 be in the same configuration as the aircraft used for testing'.

Aircraft operation

Effect of the various limitations on accidents

The applicability of the aforementioned supplements, exemptions, and limitations to the three M18A accidents are summarised in Table 4. Although there was insufficient evidence to link operations in excess of the mandated airspeed and angle of bank limitations to the accidents, the investigation report into the third accident noted that:

> Exceeding any operational limitations can affect an aircraft's handling and performance, reducing the normal operational safety margins. It can also impose significant structural loads in excess of the aircraft's design loads, reducing the aircraft's effective service life and potentially causing structural failure.

Table 4: Summary of M18 accident investigations

	200600851	AO-2008-084	AO-2011-082
Aircraft type	M18A	M18A	M18A
Operation type	Firefighting	Agricultural	Agricultural
Applied AFM Supplement No. 1	No	No	No
Applied AFM Supplement No. 16	No	No	No
Applied AFM Supplement No. 17	Yes	No	No
Applied STC SVA521	No[A]	No[A]	Yes
Applied CASA exemption	Yes	Yes[B]	No
Estimated weight range at the time of the accident	5,295 kg to 6,044 kg	5,090 kg to 5,370 kg	4,853 kg to 5,397 kg
Exceeded 15° bank angle	Yes	Yes	Yes
Exceeded airspeed limitation for an aircraft with 'dusting spraying or atomizing equipment installed'	Not applicable (equipment not installed)	Yes	Yes
Exceeded applicable airspeed limitation for increased-weight operations	Yes	Yes	Yes

[A] STC SVA521 was not approved at the time of these accidents. However, the AFM for the aircraft in AO-2008-084 included an early version of the supplement which later accompanied STC SVA521.

[B] At the time of this accident, CASA exemption EX75/08, applying specifically to M18 aircraft, was in force and permitted operations up to 6,600 kg.

Effect of speed and angle of bank on aircraft turns

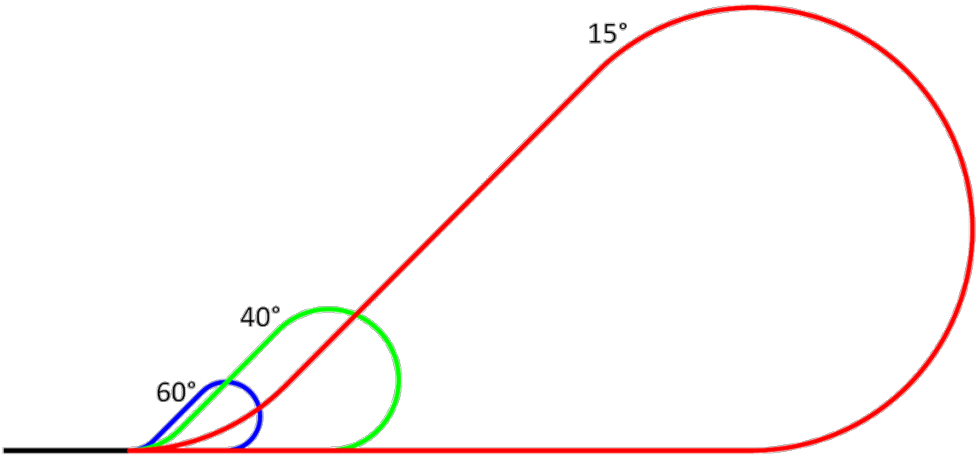
The radius of an aircraft's turn is dependent on its speed and bank angle.[12] For example, at a given speed, a level turn with a bank angle of 15° has a radius about three times that of a 40° turn and about 6.5 times that of a 60° turn. The turns will also take proportionally longer to complete due to the increasing distance travelled. At a speed of 100 kt, a steady and level turn at 15° is about 2 km in diameter.

Increasing the angle of bank in a level turn also increases the aircraft's flight loads. An aircraft flying straight and level will experience a flight load of 1 g. A 15° angle of bank turn will produce a flight load of 1.04 g, while a 60° level turn will produce a flight load of 2 g. However, this is an approximation of an actual turn as flight loads may also depend on other flight dynamics such as turbulence.

A procedure turn reverses an aircraft's course while bringing it over or near its original ground track, and is frequently used in agricultural operations such as crop spraying. A comparison of the flightpaths for three procedure turns conducted at different bank angles is shown in Figure 2. The flightpaths shown are illustrative only and do not take climbing or descending into account.

A pilot can also use alternative treatment patterns such as a 'racetrack' pattern, enabling the aircraft to use wider, more constant turns between runs.

Figure 2: Overhead view of procedure turns at different bank angles



[12] See chapter 26 of Wood, R. H. & Sweginnis, R. W., 2006. *Aircraft Accident Investigation*. 2nd ed. Wyoming, USA: Endeavour Books.

ANALYSIS

Background

The M18 Dromader was originally designed with a radial piston engine and 2,000 kg hopper capability. Subsequently, the aircraft's maximum take-off weight was increased with the use of two aircraft flight manual (AFM) supplements from the aircraft manufacturer and a third supplement that further increased the allowable aircraft weight for application in firefighting operations. A later, Australian-developed and approved Supplemental Type Certificate (STC) permitted the aircraft to operate at even higher weights when fitted with a turbine engine and larger hopper. Any particular aircraft could incorporate one, two, or none of the three applicable aircraft manufacturer's AFM supplements, with or without the STC.

These supplements and STC ultimately increased the aircraft's maximum take-off weight by up to 40% from the aircraft manufacturer's 'overload' maximum for Restricted Category operations in the M18 and M18A models, without any modifications to its structure other than to allow for the turbine engine installation. In general, such a significant increase in weight would have a serious adverse effect on the aircraft's performance, handling, and structural integrity. In the case of the 'Turbine Dromader', the increase in safety risk was mitigated by the addition of more stringent operational and maintenance limitations. These additional limitations, such as decreased bank angles, flight load factors and reduced service life were mandated via a series of aircraft manufacturer and Australian AFM supplements.

However, the effectiveness of such risk treatments relies on their correct and consistent application. The Australian Transport Safety Bureau (ATSB) identified a number of safety issues concerning the application of the more stringent operational limitations, determination of aircraft weight, and with the application by some operators of the service life reduction requirement. Separately some of these issues are relatively minor, but collectively they could lead to unnecessarily increased risk during increased-weight operations.

Aircraft operating limitations

Previous investigations found that at least three Turbine Dromaders that were involved in fatal accidents were flown beyond the aircraft's airspeed and bank angle limitations for increased-weight operations. While it may not necessarily apply to the operation of all Dromader aircraft, operators or aircraft types, it is very likely that an unknown number of Dromaders were, and continue to be flown in the agricultural role at weights for which those limitations apply. In particular, the maximum 15° bank angle limitation imposed by Australian STC SVA521 would, when applied to an agricultural operation probably affect the efficiency of the operation, to the extent that the operation could be impractical.

Adherence to the operating limitations in an aircraft's AFM, which are promulgated via aircraft placards, or that are published in other documentation is a pilot responsibility. Such publications do not normally provide the reasons why particular limits apply, or why exceeding them may have unanticipated

consequences. For example, a bank angle limitation may exist to prevent adverse handling characteristics at higher bank angles near the stall.

In addition, designers allow a safety margin between an aircraft's design limitations and its physical limitations to account for aspects of manufacture, maintenance and operation that are outside of their control, and which vary over time. In practice, a pilot who is operating to the fullest extent of his or her aircraft's published limitations might sometimes inadvertently exceed what the designers intended, but remain safe as a result of the aircraft's inherent safety margin. Whether inadvertent or otherwise, exceeding the limitations places an aircraft closer to its actual physical limitations and greatly increases the risk of other factors eroding safety margins with potentially catastrophic consequences.

Operation under Supplemental Type Certificate SVA521 at weights between 4,200 kg and 5,300 kg

The operational limitations of STC SVA521 provided for agricultural operations in M18 and M18A Dromaders at weights between 5,300 kg and 6,600 kg. The STC did not specify whether the limitations applied to an entire flight, or for the portion of a flight for which the aircraft's weight was above 5,300 kg.

In this context, operations under STC SVA521 with no additional supplements incorporated in the relevant aircraft's AFM were not affected by any additional limitations on operations between 4,200 kg (where the basic AFM limitations had effect) and when the STC had effect at 5,300 kg and above. In addition, the AFM supplements weren't mandated by the STC, meaning that any additional limitations on operations above 4,700 kg had no effect unless the supplement was separately incorporated in an aircraft's AFM by the individual operator. Finally, even if Supplement No. 1 was incorporated in an aircraft's AFM, no additional limitations applied to agricultural operations under STC SVA521 between 4,700 kg and 5,300 kg.

The result was that an operator or pilot could, under STC SVA521 and depending on the supplements that were incorporated in an aircraft's AFM, apply a variety or no operational limitations to agricultural operations in M18 and M18A Dromader aircraft at weights between 4,200 kg and 5,300 kg (Table 5). This lack of clear and unambiguous operational limitations increased the risk of their inconsistent application by operators and/or pilot's, increasing the likelihood of the unknowing erosion of engineering safety margins and aircraft life.

Table 5: Applicability of operational limitations with SVA521

<table>
<tr><th>Weight range</th><th>Basic AFM</th><th>PZL Supp. 1</th><th>PZL Supp. 16</th><th>PZL Supp. 17</th><th>AFM Supp. for SVA521</th></tr>
<tr><td>4,200 kg and below</td><td>✓</td><td rowspan="2">If incorporated</td><td rowspan="2">If incorporated and for fire-fighting only</td><td rowspan="2">If incorporated and for M18B only</td><td rowspan="2">✘</td></tr>
<tr><td>4,200 kg to 4,700 kg</td><td rowspan="3">✘</td></tr>
<tr><td>4,700 kg to 5,300 kg</td><td rowspan="2">✘</td></tr>
<tr><td>5,300 kg to 6,600 kg</td><td>✘</td><td>✘</td><td>✘</td><td>✓</td></tr>
</table>

As an example, an M18A incorporating PZL Supplement No. 1 and STC SVA521 could conduct agricultural operations at weights above 4,200 kg. In this circumstance PZL Supplements No. 16 or 17 would not be valid due to the operation and aircraft type respectively. The aircraft could operate at weights up to 6,600 kg but it would not be clear to the pilot which, if any, limitations would then apply in the 4,700 kg to 5,300 kg weight range.

Adjustment of airframe life

The approved AFM and maintenance manual supplements in support of STC SVA521 required adjustment of the airframe life for aircraft operations above 4,700 kg.

An aircraft's weight has little or no effect on some aircraft components, such as the engine and instruments, so more frequent servicing of those components might not be necessary in response to operations at increased operating weights. However, aircraft structural components and flight controls might exhibit problems as a result of such operations sooner than accounted for as part of an aircraft's certification. Any elevated component failure or other risk resulting from operations at increased operating weights could be reduced by more frequent maintenance and/or component replacement. The aircraft manufacturer's intended service life adjustment method had two effects: firstly to reduce the overall service life, and secondly to reduce the effective service intervals. The STC had a similar effect on fatigue-related service intervals.

The ATSB identified that at least one maintenance organisation applied the life adjustment incorrectly. While both methods resulted in the same reduction of total service life, they resulted in different service intervals, with the first resulting in more frequent servicing per flight hour than the second.

The ATSB did not quantify the extent to which any aircraft components required more frequent maintenance or replacement as a result of operations at increased weights. Applying only the service life reduction could lead to operations with aircraft components that should have been more regularly maintained. This increases the risk of unpredictable in-flight failure of those components and/or controls.

In addition, due to the difference in service life adjustment factors between STC SVA521 and PZL Supplement No. 16, an aircraft which incorporated both would

have ambiguous service life adjustment factors when operating between 4,700 kg and 5,300 kg. For example, an aircraft operating at 5,000 kg would use a service life adjustment factor of 1.35 under PZL Supplement No. 16 and about 1.16 under STC SVA521.

Aircraft configuration for STC SVA521

The aircraft that was used in flight tests to demonstrate regulatory compliance of STC SVA521 was reportedly fitted with vortex generators and larger elevators that were similar to those on the M18B Dromader. The original M18 and M18A Dromaders incorporated neither enhancement.

The notes for PZL Supplement No. 16, which permitted operations up to 5,300 kg, warned of a 'dynamic longitudinal instability with free control stick'. This warning was not included in PZL Supplement No. 17 for the M18B, suggesting that the longitudinal instability might have only applied to the M18 and M18A Dromaders as a result of their smaller elevators. The lack of a longitudinal instability warning in the AFM supplement for STC SVA521 suggested that the flight test aircraft did not exhibit that type of instability. This was consistent with its being fitted with larger elevators.

Ultimately, STC SVA521 and its associated documentation did not require the vortex generators or enlarged elevators to be fitted to an aircraft that was being operated in accordance with the STC. As a result, there was no assurance that a Dromader operating under the STC would have similar handling and performance characteristics as the flight test aircraft, and limited assurance that such an aircraft would exhibit acceptable handling and performance characteristics.

Hopper level sight gauge

The application of appropriate limitations and maintenance requirements in different weight ranges is dependent upon a reasonably accurate estimation of an aircraft's weight prior to, and during, a flight. In an aircraft with the enlarged hopper modification incorporated, this estimation relies on the use of an appropriately recalibrated in-cockpit hopper level sight gauge. Recalibration of the sight gauge was not required by the Engineering Order for the hopper modification. This increased the potential for operations at an uncertain aircraft operating weight, and therefore risk of operations in excess of the published aircraft limits.

FINDINGS

From the evidence available, the following findings are made with respect to the operation of M18 Turbine Dromader aircraft and should not be read as apportioning blame or liability to any particular organisation or individual.

Safety factors

- M18 Dromader aircraft were being operated in the agricultural role at weights for which a 15° bank angle limitation had effect, whereas the nature of agricultural operations increased the risk of pilots exceeding that limitation. *[Significant safety issue]*
- There was a potential, depending on the supplements that were incorporated in an aircraft's flight manual, for pilots and/or operators to apply incorrect operational limitations to agricultural operations in M18 and M18A Dromader aircraft at weights between 4,200 kg and 5,300 kg. This increased the risk of their inconsistent application to these operations, and the likelihood of the unknowing erosion of engineering safety margins and aircraft life. *[Minor safety issue]*
- At least one maintenance organisation applied the service life factoring required by Supplemental Type Certificate SVA521 incorrectly, increasing the risk of premature and undetected in-flight failure of aircraft structure, components and/or controls.
- There was limited assurance that M18 and M18A Dromader aircraft incorporating Supplemental Type Certificate SVA521 would exhibit acceptable handling and performance characteristics if not fitted with vortex generators and M18B standard elevators. *[Significant safety issue]*
- Aircraft operations with an enlarged hopper but no associated recalibration of the hopper level sight gauge increased the potential for operations at an uncertain aircraft operating weight, and therefore risk of operations in excess of the published aircraft limitations. *[Minor safety issue]*

SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections 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.

All of the directly involved parties were provided with a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

Safety issues related to Supplemental Type Certificate SVA521

Safety issues

- M18 Dromader aircraft were being operated in the agricultural role at weights for which a 15° bank angle limitation had effect, whereas the nature of agricultural operations increased the risk of pilots exceeding that limitation. *[Significant safety issue]*
- There was a potential, depending on the supplements that were incorporated in an aircraft's flight manual, for pilots and/or operators to apply incorrect operational limitations to agricultural operations in M18 and M18A Dromader aircraft at weights between 4,200 kg and 5,300 kg. This increased the risk of their inconsistent application to these operations, and the likelihood of the unknowing erosion of engineering safety margins and aircraft life. *[Minor safety issue]*
- There was limited assurance that M18 and M18A Dromader aircraft incorporating Supplemental Type Certificate SVA521 would exhibit acceptable handling and performance characteristics if not fitted with vortex generators and M18B standard elevators, in particular that the risk of longitudinal instability had been reliably addressed. *[Significant safety issue]*

Actions taken by the owner and developer of Supplemental Type Certificate SVA521

The owner and developer of Supplemental Type Certificate (STC) SVA521 reported that pending Civil Aviation Safety Authority (CASA) approval, they were in the process of amending it as follows:

- increasing the maximum permitted bank angle to 45°
- clarifying the applicability of aircraft flight manual limitations for operations between 4,200 kg and 5,300 kg
- including the fitment of vortex generators and M18B standard elevators as prerequisites for applying the STC.

ATSB assessment of actions by the owner and developer of Supplemental Type Certificate SVA521

The ATSB is satisfied that the proposed safety action will, when implemented, adequately address the safety issues.

Actions taken by the Civil Aviation Safety Authority

CASA advised that it will ensure that the:

- SVA521 Engineering Order and aircraft flight manual (AFM) supplement are amended to add M18B standard elevators and vortex generators as required modifications
- applicant and their engineering organisation amends the SVA521 AFM supplement to include data covering all Restricted Category operations up to 6,600 kg (that is, from 4,200 kg to 6,600 kg). This will obviate the need for multiple AFM supplements and simplify the AFM overall, thus improving safety.

ATSB assessment of action by the Civil Aviation Safety Authority

The ATSB is satisfied that the proposed safety actions will, when implemented, adequately address the safety issues.

APPENDIX A: COMPARISON OF THE TWO INTERPRETATIONS OF THE AIRCRAFT SERVICE LIFE REDUCTION FACTOR

Table 6 compares the results of each interpretation of the aircraft service life reduction factor as applied to a hypothetical aircraft's maintenance schedule and airframe life. This example is based on a flight of 1.2 hours duration and a take-off weight of 6,400 kg. Method 1 is the method intended by the owner/developer of Supplemental Type Certificate SVA521. Method 2 is a method reported to have been used by one maintenance organisation.

Table 6: Service life reduction examples

Item	Method 1	Method 2
Maximum airframe life before flight [A]	5,000 hours	
Aircraft time in service before flight [A]	4,000 hours[B]	
Time to next service before flight [A]	100 hours	
Recorded aircraft take-off weight [A]	6,400 kg	
Correction factor (from Table 2)	2.3	
Actual flight time [A]	1.2 hours	
Adjusted flight time	(1.2 × 2.3) = 2.76 hours	
Aircraft time in service after flight	(4,000 + 1.2) = 4,001.2 hours	
Adjustment method	A second log of 'airframe fatigue' time in service is kept, and 2.76 hours is added to it after the flight. 'Airframe fatigue' time in service = 4,002.76 hours	The difference between adjusted flight time and actual flight time is subtracted from the airframe life. Airframe life = 5,000 - (2.76 – 1.2) = 4,998.44 hours
Airframe life remaining	5,000 – 4,002.76 = 997.24 hours	4,998.44 – 4,001.2 =997.24 hours
Time to next airframe-fatigue-related service after flight	(time to next service minus 'airframe fatigue' time) = (100 - 2.76) = 97.24 hours	(time to next service minus recorded flight time) = (100 - 1.2) = 98.8 hours

[A] Example only and not intended to represent an actual aircraft or operation.

[B] Method 1 uses a separate log of 'airframe fatigue' time in service, which is assumed in this example to be initially the same as the actual time in service.

APPENDIX B: SOURCES AND SUBMISSIONS

Sources of information

The sources of information during the investigation included:

- the Civil Aviation Safety Authority (CASA)
- the owner of Australian Supplemental Type Certificate (STC) SVA521
- the developer of Australian STC SVA521
- PZL Mielec
- PZL M18 Dromader documentation.

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (ATSB) may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to CASA, the aircraft manufacturer, the owner and developer of Australian STC SVA521, and the Aerial Agricultural Association of Australia (AAAA).

Submissions were received from CASA, the owner and developer of Australian STC SVA521, and the AAAA. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

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Investigation

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Aviation Safety Issue Investigation
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