Peacetime Attrition Analysis of Selected Unmanned Aerial Vehicles

Esther Yu
Directorate of Air Staff Operational Research

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Abstract

This research was conducted in support of two upcoming studies: a study regarding manned versus unmanned aircraft for various defence missions and tasks, and a review of peacetime attrition for various classes of aircraft, including both manned and unmanned. The attrition rates for selected unmanned aerial vehicles (UAVs), such as Predator, Pioneer, and Hunter were researched and compared to the Canadian Forces' experience with the Sperwer system. Attrition will be dependent on the experience level of the organization employing the aircraft, and the maturity of the aircraft system itself. This relationship is investigated using linear regression analysis.

Résumé

La présente recherche avait pour but de soutenir deux études à venir : une première étude portant sur les avantages et les inconvénients respectifs des aéronefs avec équipage et des engins télépilotés pour l'exécution de divers types de missions et de tâches de défense; et une deuxième étude portant sur les statistiques d'attrition en temps de paix de diverses catégories d'aéronefs avec équipage et d'engins télépilotés. On a procédé à l'étude des taux d'attrition d'engins télépilotés sélectionnés, comme le Predator, le Pioneer et le Hunter et on les a comparés à ceux que les Forces canadiennes ont connus avec le Sperwer. Les taux d'attrition reposent principalement sur le niveau d'expérience de l'organisme qui utilise l'aéronef et sur le degré de maturité du système lui-même. L'analyse a été effectuée à l'aide d'un modèle de régression linéaire.

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Executive Summary

Unmanned aerial vehicles (UAVs) are becoming more and more capable. UAVs have largely been employed in surveillance roles to date, taking advantage of the longer endurance of an unmanned platform. Removing the human from the aircraft not only removes the potential risk to the life of the pilot, but permits the space and weight allotment for the human to be used for payload or fuel, and permits a degree of miniaturization of the entire platform, a distinct covertness advantage.

In theory, removing the human also should lessen the flight safety demands on the aircraft and its systems, making it potentially cheaper to build. On the other hand, it may lead to more aircraft losses as a remote pilot will struggle to effectively replace the fully sensored, quick responding human decision-maker on board when flight problems arise. This analysis attempts to characterize the losses that can be expected with UAV systems by presenting and analyzing statistics on existing systems, including the Canadian Forces (CF) Sperwer system which has been operated in Afghanistan.

The data collected for this study ranges from sources found on the Internet to Departmental data sets that have been made available on Sperwer.

Using a linear regression model, analysis of the Sperwer data shows an accident rate experienced in the Afghanistan theatre of operations that was comparable to the overall US experience with the (slightly smaller) Pioneer UAV. The US Hunter and Predator UAVs, both larger air vehicles than Sperwer, have experienced lower accident rates. As noted by the US Office of the Secretary of Defence in its UAV Reliability Study published in 2003, UAVs still need to “improve by one or two orders of magnitude to reach and equivalent level of safety with manned aircraft”.

All UAV systems investigated showed improving accident rates over time, consistent with the early to middle stages in the life cycle under the ‘bathtub curve’ model.

The accidents with Sperwer were primarily (about two thirds) due to system related causes, rather than due to human error or weather/environmental reasons. Human error was the cause of about half of Predator accidents, but has been only a minor cause of accidents in Sperwer operations.

Sommaire

Les capacités des engins télépilotés sont en nette croissance. Jusqu'à maintenant, ces engins ont surtout été utilisés dans des rôles de surveillance qui tiraient profit de la grande endurance d'une plate forme sans équipage de bord. Le télépilotage permet non seulement d'assurer la sécurité de l'équipage, mais également d'alléger considérablement l'appareil et de libérer de l'espace pour transporter davantage de carburant et une plus grande charge utile. On peut aussi grandement miniaturiser la plate forme, ce qui constitue un net avantage en matière de furtivité.

Théoriquement, le fait de supprimer toute présence humaine à bord d'un aéronef devrait permettre de diminuer les contraintes relatives à la sécurité de l'appareil et de ses systèmes, et également de réduire ses coûts de construction. Par contre, une telle solution peut accroître le risque de perte de l'aéronef car, lorsqu'il doit régler des problèmes de pilotage, le télépilote ne dispose pas des mêmes éléments de perception sensorielle et de la même rapidité d'exécution que s'il était à bord. La présente analyse vise à caractériser les pertes auxquelles on peut s'attendre avec les systèmes d'engins télépilotés en présentant et en analysant les statistiques sur les systèmes existants, notamment le système Sperwer des Forces canadiennes (FC), lequel est utilisé en Afghanistan.

Les données recueillies pour cette étude proviennent de diverses sources allant de l'Internet aux ensembles de données ministérielles disponibles concernant le Sperwer.

L'analyse des données relatives au Sperwer, fondée sur un modèle de régression linéaire, révèle que le taux d'accident subi sur le théâtre des opérations de l'Afghanistan est globalement comparable à celui qu'ont connu les États Unis avec l'engin télépiloté Pioneer, lequel est légèrement plus petit que le Sperwer. Les engins télépilotés Hunter et Predator des États Unis, tous deux de plus grande taille que le Sperwer, ont subi des taux d'accident inférieurs. Comme l'a noté l'Office of the Secretary of Defence des États Unis dans son étude de fiabilité des engins télépilotés (UAV Reliability Study) publiée en 2003, les engins télépilotés doivent encore « s'améliorer d'un ou de deux ordres de grandeur pour atteindre un niveau de sécurité équivalent à celui des aéronefs avec équipage ».

Tous les systèmes d'engins télépilotés étudiés ont connu une amélioration graduelle de leur taux d'accident avec le temps, ce qui est conforme au modèle statistique de courbure en baignoire correspondant aux stades initial et intermédiaire de leur cycle de vie.

Les causes des accidents mettant en cause le Sperwer ont été principalement (environ aux deux tiers) liées au système, plutôt qu'à l'erreur humaine ou aux conditions météorologiques ou environnementales. L'erreur humaine a été la cause de près de la moitié des accidents du Predator, mais elle n'a été qu'une cause mineure des accidents du Sperwer.

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1 Introduction

1.1 Background

1. As technology evolves, unmanned aerial vehicles (UAV) are becoming more and more capable. UAVs are largely employed in surveillance roles to date, taking advantage of higher endurance and longer ranges of an unmanned platform. Currently, general aviation aircraft still have a better mishap rate than the UAV. On the other hand, accident rates for UAVs have been coming down. As the UAV technology has matured, there has been a "steady decline over the past half century" [1].

2. One of the primary purposes of an unmanned aircraft is to avoid having pilots in harm's way. For this reason, the operator, or pilot, is in another location from where s/he can operate the UAV. Some UAVs start off with a pre-programmed route and contain waypoints where the UAV operator can circle around that waypoint if something below becomes of interest.

3. A higher attrition rate for UAVs compared to manned aircraft can be due to both physical aircraft and human operator factors. Given that the aircraft does not have to accommodate a human being, it can be made smaller. By making the aircraft smaller, it is easier to stay undetected in the sky for longer compared to a larger aircraft. However, due to the size of the UAV, it will encounter different environmental issues that designers and operators may not have had experience with in manned aircraft. One prime example is wind. A gust of wind may affect a larger aircraft only slightly and a pilot can adjust for it, however with a small aircraft similar to a UAV, this may be especially difficult if the pilot is operating the UAV from a distance and cannot "feel" the wind. This is a physical characteristic of smaller UAV which can cause accidents/incidents.

4. However, not all accidents/incidents are caused by the physical structure of the UAV. Some UAV related problems are categorized as system errors. The Sperwer system, for example, uses a parachute to land and there have been cases were the aircraft crash landed because deployment of the parachute was unsuccessful. These crashes could be the cause of design due to the fact that it is an unmanned vehicle; certain issues such as crew safety were not considered to make a more robust aircraft.

1.2 Motivation for Study

5. This study will be used to support a couple of broader studies such as benefits of having a manned vs. unmanned aircraft across the spectrum of defence missions and tasks, and a review of the peacetime attrition rates experienced by various classes of aircraft. Both studies will require information regarding UAV attrition as part of the larger studies.

6. It is important to understand how systems from the Global Hawk to the micro UAVs fail in comparison to incidents occurring with manned aircraft even if human life is not lost. If UAVs continue to have a higher attrition rate than manned aircraft it will impact their operational utility, costs, and other major factors.

2 Methodology

2.1 Data Gathering

7. The data collected for this study ranges from sources found through an internet search, to data made available from departmental sources. Results from the Internet search identified articles ranging from scientific magazines to press releases. However, there were only limited sources of UAV attrition data located on the web. One particularly useful source was the United States Office of Secretary of Defence which has posted its UAV Reliability Study [2]. Another helpful source, also an American source, is the USAF Safety Center website, which contains accident reports for the Predator and Global Hawk UAVs [6].

8. The most accurate data acquired was from departmental sources for Canadian Forces (CF) employment of the Sperwer UAV in Afghanistan. Most information located through the Internet was anecdotal in nature. The results section of this study will further explain the attrition rates and reasons for accidents/incidents for the Sperwer UAV. However, this knowledge can also be applied to similar UAVs.

9. Executive summaries of USAF Accident Investigation Board (AIB) reports on the MQ-1 Predator UAV were gathered from Reference [6], as posted up to July 2008. These report on any Class 'A' accident, defined as one resulting in loss of life, a total permanent disability, loss of an aircraft, or damage exceeding one million dollars [6]. These accident reports were reviewed and the general cause of the accident categorized. The results are summarized in Table A5 of Annex A. Note that RQ-4 Global Hawk accidents are also captured here, but were in insufficient number to generate useful statistics. The flying rates for the Global Hawk and the Predator are not known precisely, but can be estimated from media reports (e.g. Jane's).

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2.2 Data Analysis

10. The Sperwer data included the number of flying hours per month and descriptions of each flying accident which was incurred that month. The idea was to try to discover a relationship between the number of flight hours and the number of accidents. To help find a relationship, the Statistica statistical analysis software package was used.

11. Within Statistica, there are many options of how to best fit the data to come up with a relationship between two variables. The Linear Regression Model was chosen simply because the interest of this study was to try to find a relationship between the flight hours and the number of accidents and to try to see a trend. Many variations of how the data could be represented were used, but each time the *r-squared* ratio was quite small. The *r-squared* ratio describes what fraction of the variability observed in the data can be accounted for by introducing the trend line.

12. Before plotting the accident rates, the raw data must be converted in a usable form. 'Accident rate' is defined as the number of accidents per flying hour.

3 Results

3.1 The Bathtub Model

13. A wide range of electronic and mechanical devices experience a similar pattern for failures, where failures will occur more frequently early in the system's life, reduce and level off as the equipment matures and users gain experience in using it, and then increase again as the system reaches the end of its life. Because the shape of this graph looks similar to that of a bathtub it has been characterized as the 'bathtub' curve, shown notionally in Figure 1. Depending on the complexity of the system the first region can last several months to several years. The next region is the bottom flat portion of the bathtub and is where the system will spend most of its life span. If the product has survived through the flat portion of the curve then it will reach the end of its life at which point the failure rate beings to increase again due to degradation failures.

14. The bathtub curve should be a reasonable model for the CF experience with Sperwer. The Army acquired and deployed this system to Afghanistan in October 2003. In March 2006 the Air Force took over operation of the system and implemented a comprehensive recording system for operational and maintenance data. Comparable data is not available for the first 2.5 years of service for the system, so the analysis presented here will rely on the Air Force data. The 'raw' data released to the author by the Weapon System Manager in DGAEPM is listed in Annex A. Since the Sperwer is still a relatively young UAV, the weapon system management team believes that this system is still in the early part of the flat portion of the bathtub curve (see 'Area of Interest' in Figure 1).

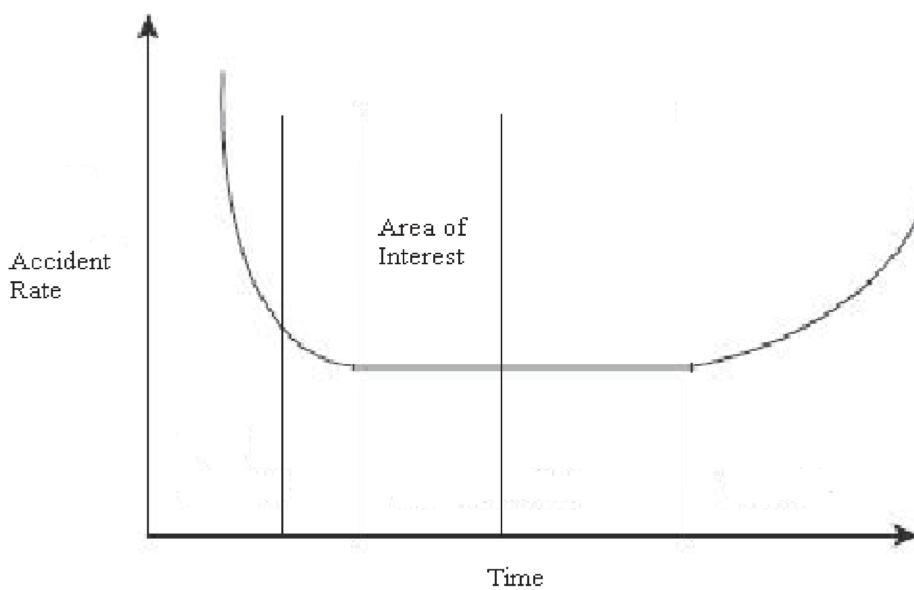

Figure 1: Notional Bathtub curve

3.2 Sperwer Accident Rate

15. The number of operational flying hours and number of Category 'A', 'B', and 'C' accidents that occurred between March 2006 and July 2008 is presented, by month, in Figure 2. The information was provided at reference [7].

16. The Directorate of Flight Safety (DFS) defines each category based on the severity of accident. CAT A is an aircraft which is destroyed or missing and/or involves fatal injury or missing personnel. CAT B is described as very serious aircraft damage and/or very serious injury or illness to personnel. Lastly, CAT C is described as serious damage to aircraft and/or personnel. An accident is defined as any occurrence of a CAT A, B or C event. Note that a CAT A accident as defined here is not exactly the same as the USAF definition, but is very similar.

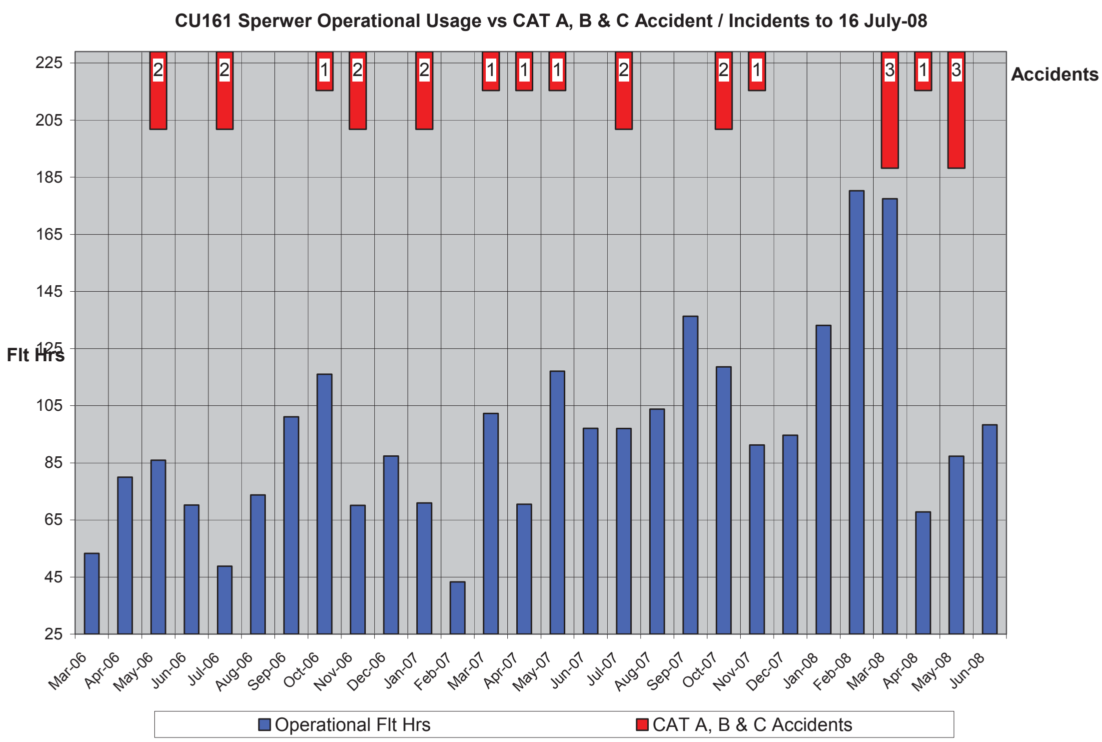

Figure 2: Sperwer Operational Usage vs. Accidents to 17 July 2008

17. The breakdown of the different type of accidents (CAT A, B, or C), by month, is presented in Figure 3.

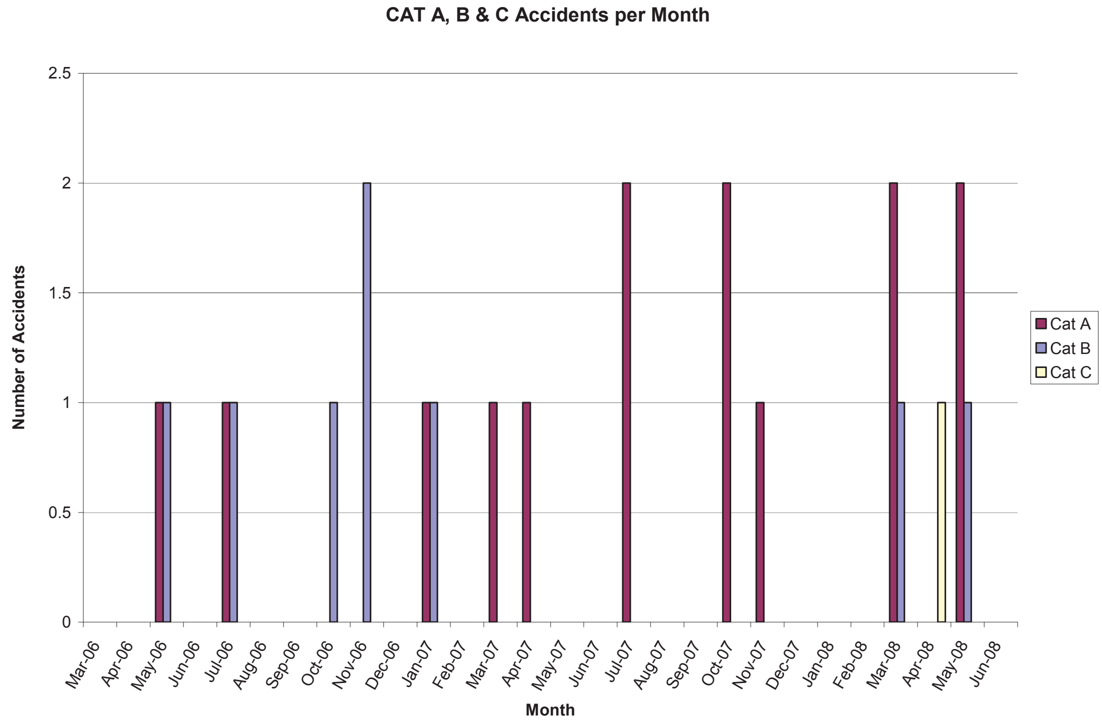

Figure 3: Accident CAT A, B and C per Month

18. In some texts the accident rate (AR) is calculated per 100,000 flying hours. To keep things simple it was chosen here to simply graph the AR per flying hour. Figure 4 is a plot of the rate of accidents over time. The regression line fit to the data suggests that accidents over time are slightly decreasing. However, the sample size is small and the data are quite variable, so this is not a statistically significant finding.

19. The slightly improving trend is consistent with the "bathtub" model. The data given is only for a portion of the life of the Sperwer fleet, as shown notionally in Figure 1. As the life span of the system progresses one would expect reliability to continue to improve.

3.3 UAV Accident Comparisons

20. The US Office of the Secretary of Defence published its *Unmanned Aerial Vehicle Reliability Study* in 2003 [2]. It presented accident rates for the primary military UAV systems employed in the United States. The three major systems assessed were the RQ-1 Predator, RQ-2 Pioneer, and RQ-5 Hunter. Table 1 compares the basic attributes of (the 'A' variants of) all four UAV systems.

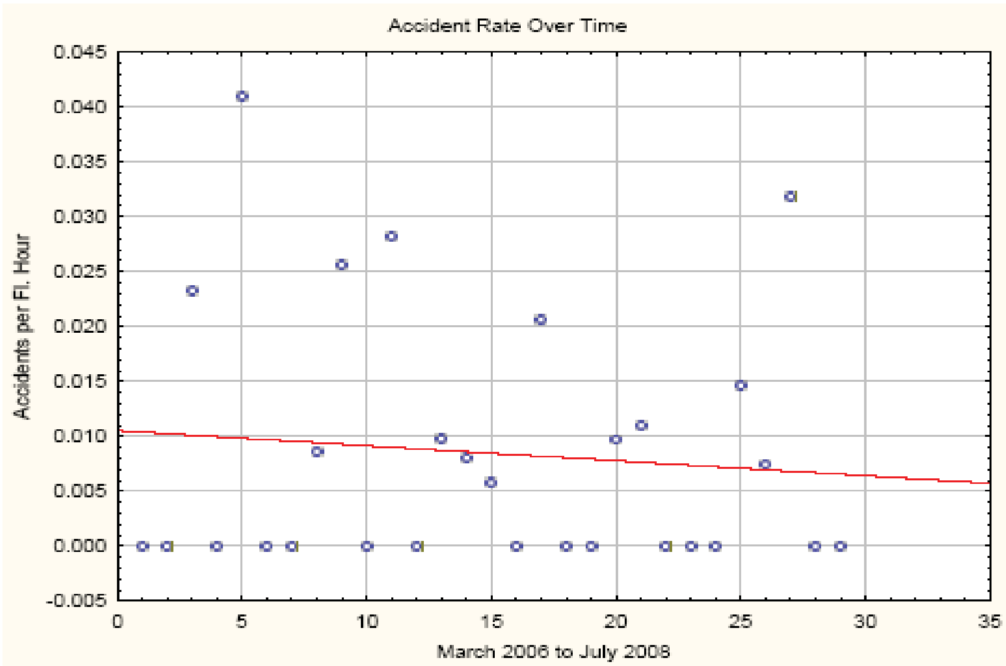

Figure 4: Accident Rate over Time for Sperwer UAV

Table 1: Comparison of Predator, Pioneer, Hunter, and Sperwer UAVs

UAV System	Gross Weight	Endurance	First Flight
Predator (RQ-1A)	1043 kg	40 hrs	1994
Pioneer (RQ-2)	190 kg	6.5 hrs	1986
Hunter (RQ-5A)	726 kg	12 hrs	1990
Sperwer	350 kg	6 hrs	1996

21. Figure 5 presents the accident rates per 100,000 flying hours for Predator, Pioneer, and Hunter drawn from Reference [2]. The raw data is listed in Annex A. These UAVs also exhibit accident rate trends that are generally consistent with the bathtub curve model, where accident rates drop over time as the systems mature and the operators gain familiarity with them. The data is only shown for Pioneer beginning in 1990 to keep the vertical scale reasonable. Between the year it came into service (1986) and 1989 it was experiencing 1,000 to 2,000 accidents per 100,000 flying hours [2]. It is noteworthy that the heavier UAV (Predator) experienced the lowest accident rate and the lightest (Pioneer) experienced the highest. Note that none of the systems have been in service long enough to exhibit the end-of-service rise in accidents that the bathtub curve would predict.

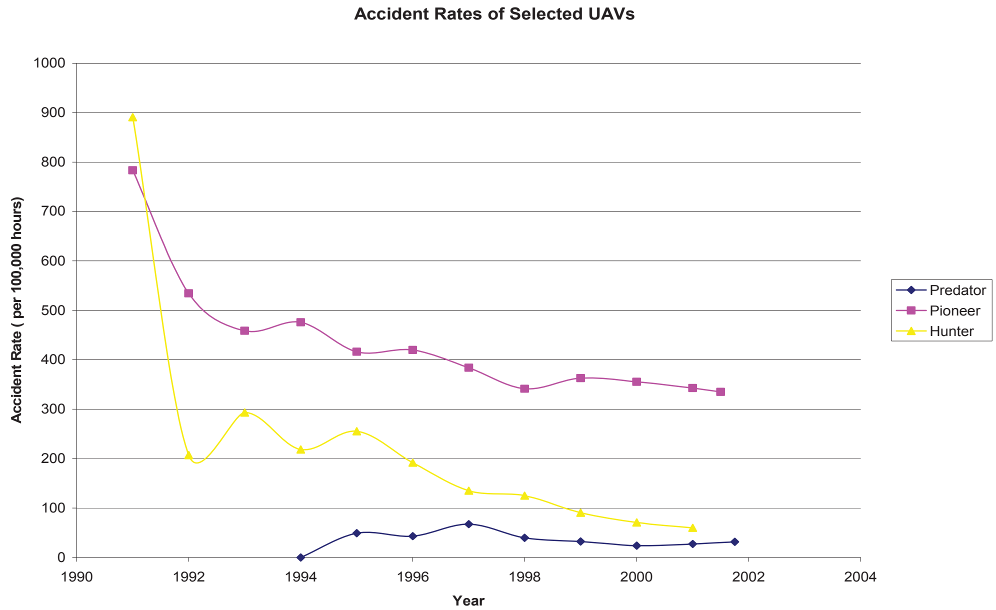

Figure 5: Accident Rate over Time for Selected UAVs

22. These figures can be compared to those typical of general aviation aircraft at about 1 mishap per 100,000 flying hours [2]. To quote Reference [2], “the reliability of UAVs needs to improve by one to two orders of magnitude to reach an equivalent level of safety with manned aircraft”.

23. At 0.006 to 0.010 losses per flying hour (600 to 1000 accidents per 100,000 flying hours) it would seem that the Canadian Sperwer experience is similar to that of the (smaller) US Pioneer. Direct comparison isn’t really possible as the American Class A accident definition is not equivalent to the combined Canadian CAT A, B, and C definitions, and the two UAVs may have been operated in quite different environments (weather, elevation) as well.

24. It is useful to look at environmental effects in more detail. Heat and altitude both reduce air density and degrade both the performance of an aircraft aerodynamically and the performance of normally aspirated engines. The ‘high and hot’ conditions found in Afghanistan during the summer (Kandahar airfield has an elevation of 3,330 feet above sea level and temperatures can reach the 40-50 degree Celsius range during summer) can significantly increase the launch speed and climb performance demands on a UAV. The Sperwer accident statistics were aggregated by season (monthly) to see if this phenomenon was apparent, and the results are presented in Figure 6. Accident rates were indeed highest in the spring and early summer months (March, April, May, and July), with fully two-thirds of all accidents happening in the 6-month period between March and August.

25. At high temperatures the Sperwer can experience fuel pump problems [7]. Fuel initially is a liquid; however at such high temperatures and altitudes the fuel becomes a gas and causes engine problems. The engine problem caused by such high temperatures is categorized as a ‘system’ problem. About 67% (36/54) of the total accidents noted were caused by a system problem for the Sperwer UAV.

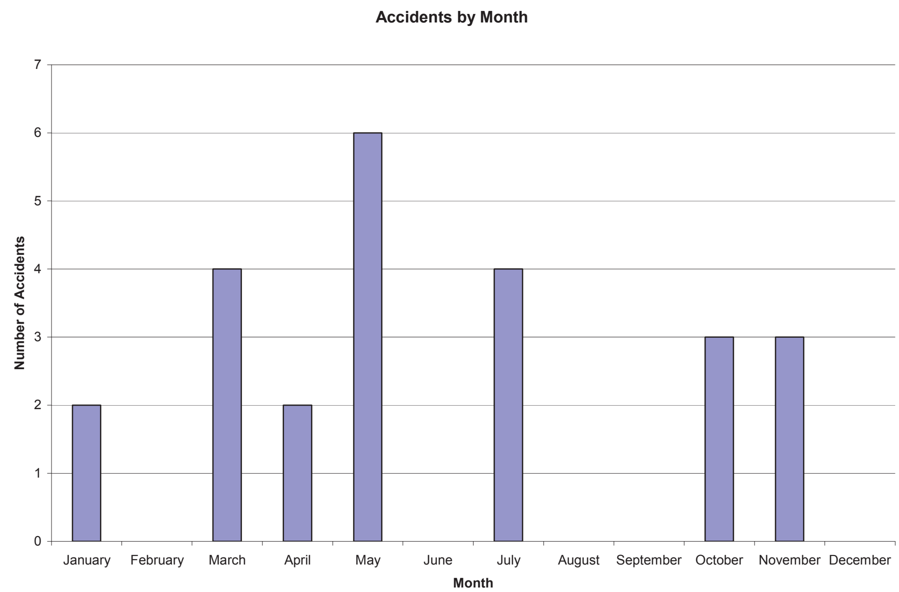

Figure 6: Accidents by Month for Sperwer UAV

26. The Accident Investigation Board reports for Predator from [6] were reviewed by the author and the cause of the accident was categorized under the following headings: Pilot Error, Engine, Manufacturer, Weather/Environmental, and Control Loss - Other. The operational situation was also noted as Training, Operational, or Test/Check Flight. The results are presented in Table A5 in Annex A. A total of 21% (5/24) of Predator accidents were caused by engine failure. However, grouping all system problems together (Engine, Manufacturer, and Control Loss - Other) gives a total of 38% (9/24) system related accidents compared to the 67% that the Sperwer UAV encountered.

27. Another major factor to contribute to UAV accidents is the human component. A study done by Kevin W. Williams, Reference [3], explains that the human errors are largely due to how the pilot/operator is interfaced with the actual aircraft. Flying a UAV can be a difficult adjustment for pilots due to the fact that the pilot must operate the aircraft at a distance and is separated from the plane. This allows for calmer judgment; however it dulls the pilot's intuition and the ability to "fly by the seat of their pants". It also gives the impression that the aircraft is commanded and not flown which provides a paradigm shift for most pilots to grasp.

28. For the Sperwer UAV, 18.5% (10/54) accidents were attributed to human error. This number is much lower than the Predator UAV with 54% (13/24) Class A accidents attributable to human or pilot error. In regards to the Sperwer, most incidents are technical issues and any significant human errors are a result of carelessness such as the mission commander pressing an incorrect button. Another example of human error is a miscalculation of fuel or a technical person not following proper procedure. Although 18.5% of the accidents for the Sperwer UAV were caused by human errors, none were listed as serious (not CAT A, B or C).

4 Conclusions

29. Analysis of the Sperwer data shows an accident rate experienced in the Afghanistan theatre of operations that was comparable to the overall US experience with the (slightly smaller) Pioneer UAV. The US Hunter and Predator UAVs, both larger than Sperwer, have experienced lower accident rates. As noted by the US Office of the Secretary of Defence in Reference [2], UAVs still need to "improve by one or two orders of magnitude to reach and equivalent level of safety with manned aircraft".

30. All UAV systems investigated show improving accident rates over time, consistent with the early to middle stages in the life cycle under the 'bathtub curve' model.

31. The accidents with Sperwer were primarily (about two thirds) due to system related causes, rather than due to human error or weather/environmental reasons. Human error was the cause of about half of Predator accidents, but has been only a minor cause of accidents in Sperwer operations.

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Annex A UAV Raw Data

A.1 Sperwer UAV Data

Table A1: Sperwer UAV Operational Flight Hours and Accidents by Month. [7]

Month	Operational Flt Hrs	Total Flt Hrs	CAT A, B & C Accidents
Mar-06	53	53	
Apr-06	80	80	
May-06	86	86	2
Jun-06	70	70	
Jul-06	49	49	2
Aug-06	74	74	
Sep-06	101	101	
Oct-06	116	116	1
Nov-06	70	78	2
Dec-06	87	87	
Jan-07	71	71	2
Feb-07	43	43	
Mar-07	102	102	1
Apr-07	71	125	1
May-07	117	174	1
Jun-07	97	97	
Jul-07	97	97	2
Aug-07	104	104	
Sep-07	136	199	
Oct-07	119	206	2
Nov-07	91	91	1
Dec-07	95	95	
Jan-08	133	133	
Feb-08	180	180	
Mar-08	178	205	3
Apr-08	68	134	1
May-08	87	94	3
Jun-08	98	98	
Jul-08	48	48	

A.2 Predator, Pioneer and Hunter UAV Data

Table A2: Predator UAV Cumulative Operational Flight Hours and Accidents Over Time [2]

Year	Cumulative Hours	Cumulative Accidents	Rate (per 100,000 hours)
1994	168	0	0
1995	2,027	1	49.3
1996	4,654	2	43.0
1997	7,406	5	67.5
1998	12,600	5	39.7
1999	21,738	7	32.2
2000	33,416	8	23.9
2001	43,764	12	27.4
2002 (3rd Qtr)	53,745	17	31.6

Table A3: Pioneer UAV Cumulative Operational Flight Hours and Accidents Over Time [2]

Year	Cumulative Hours	Cumulative Accidents	Rate (per 100,000 hours)
1986	96	9	9,375.0
1987	527	14	2,656.5
1988	1,516	22	1,451.2
1989	2,811	27	960.5
1990	4,150	38	915.7
1991	5,234	41	783.3
1992	7,672	41	534.4
1993	8,940	41	458.6
1994	10,508	50	475.8
1995	12,260	51	416.0
1996	13,817	58	419.8
1997	15,894	61	383.8
1998	17,867	61	341.4
1999	20,114	73	362.9
2000	21,383	76	355.4
2001	22,474	77	342.6
2002 (1st Qtr)	22,994	77	334.9

Table A4: Hunter UAV Operational Cumulative Flight Hours and Accidents Over Time [2]

Year	Cumulative Hours	Cumulative Accidents	Rate (per 100,000 hours)
1991	225	2	890.9
1992	966	2	207.1
1993	1,365	4	293.0
1994	2,291	5	218.2
1995	3,526	9	255.2
1996	4,697	9	191.6
1997	6,662	9	135.1
1998	8,011	10	124.8
1999	13,235	12	90.7
2000	16,985	12	70.7
2001	20,063	12	59.8

Table A5: Predator Accident Summary from Accident/Incident Reports. [6]

Accident	Occurrence	Accident During	Occurrence
Pilot Error	13	Training	7
Engine	5	Operational	12
Weather/Environmental	2	Test/Check Flight	5
Manufacturer	2		
Control Loss – Other	2		

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This research was conducted in support of two upcoming studies: a study regarding manned versus unmanned aircraft for various defence missions and tasks, and a review of peacetime attrition for various classes of aircraft, including both manned and unmanned. The attrition rates for selected unmanned aerial vehicles (UAVs), such as Predator, Pioneer, and Hunter were researched and compared to the Canadian Forces' experience with the Sperwer system. Attrition will be dependent on the experience level of the organization employing the aircraft, and the maturity of the aircraft system itself. This relationship is investigated using linear regression analysis.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Attrition rates, Unmanned Aerial Vehicles, UAV, Sperwer UAV, Predator UAV, Hunter UAV, Pioneer UAV

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