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Research Report

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Parametric Flyaway Cost Estimating Relationships for Manned and Remotely Piloted Military Aircraft

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Preface

Over the past decade, the services have become more reliant on remotely piloted aircraft, particularly in the area of intelligence, surveillance, and reconnaissance. To inform Air Force decisionmakers on the cost differences of manned and remotely piloted aircraft, researchers compiled data for 30 different military fixed-wing aircraft—five of which are remotely piloted—and extrapolated the average unit flyaway cost associated with producing the first 100 units of each platform. From these data, parametric cost-estimating relationships that vary with aircraft characteristics, including empty weight, whether the aircraft has stealth technology, and whether the aircraft is manned or remotely piloted, were developed using regression analysis. This report summarizes the findings of this analysis.

This research was sponsored by Maj Gen Paul "PJ" Johnson (Ret.) (AF/A5R). It was conducted over the course of fiscal year 2015 as part of a broader effort to examine life-cycle cost differences for manned and remotely piloted ISR aircraft. The findings of the overall effort are presented in the following report:

- Thomas Light, Obaid Younossi, John A. Ausink, Clifford A. Grammich, Thomas Hamilton, Mark A. Lorell, H. G. Massey, Shane Tierney, Fred Timson, and John Wallace, *Comparison of Cost Drivers for Manned and Remotely Piloted Intelligence, Surveillance, and Reconnaissance Aircraft Systems*, Santa Monica, Calif.: RAND Corporation, 2017, Not available to the public.

This report represents a summary of analysis presented in Chapter Three of the above report. It should be of interest to Air Force personnel for estimating the cost of acquiring military aircraft and understanding how those costs differ with the characteristics of the aircraft.

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Research is conducted in four programs: Force Modernization and Employment; Manpower, Personnel, and Training; Resource Management; and Strategy and Doctrine. The research reported here was prepared under contract FA7014-06-C-0001.

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This report documents work originally shared with the U.S. Air Force on August 12, 2015. The draft report, issued on September 30, 2015, was reviewed by formal peer reviewers and U.S. Air Force subject-matter experts.

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Summary

Issue

Over the past decade, the services have become more reliant on remotely piloted aircraft (RPA), particularly in the area of intelligence, surveillance, and reconnaissance (ISR). As part of a broader project to assess differences in life-cycle costs, RAND Project AIR FORCE researchers analyzed the extent to which RPA unit flyaway costs differ from those of manned aircraft.

Approach

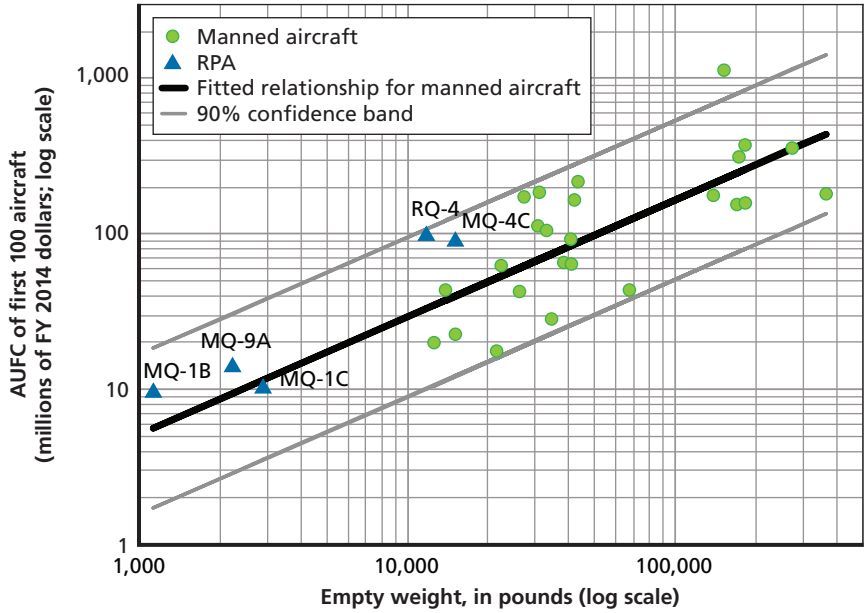
To support this analysis, researchers compiled data for 30 different military fixed-wing aircraft—five of which are remotely piloted—and extrapolated the average unit flyaway cost (AUFC) associated with producing the first 100 units of each platform.[1]

Conclusions

As suggested by Figure S.1, three of the RPA platforms have a much-lower empty weight than any of the manned platforms in our sample,

[1] For the RPA, the unit flyaway cost includes the procurement costs associated with ground control stations and data links required to pilot the aircraft.

Figure S.1
Relationship Between Aircraft Empty Weight and AUFC



but the RPA flyaway costs tend to follow the same relationship with respect to empty weight as the manned aircraft. We conclude that the family of RPA systems included in this analysis is not considerably different from manned aircraft from a flyaway cost perspective, with much of the difference in cost across platforms explained by the empty weight of the aircraft. The absence of an onboard crew allows RPAs to be built smaller and lighter than manned aircraft alternatives, particularly for compact and light payloads, which can result in cost savings.

We conducted further analysis to control for other factors affecting flyaway costs, such as whether the aircraft is stealthy, the number of aircraft procured per year, the year of first delivery, and the aircraft mission area (i.e., bomber, fighter, mobility, or ISR). Our statistical findings suggest that the unit flyaway costs of military RPAs are not statistically different from those observed for manned military aircraft after controlling for other factors. Factors besides empty weight

that correlate strongly with flyaway costs include the incorporation of stealth technology into the aircraft design and the number of aircraft produced per year.

Acknowledgments

We appreciate the support of Maj Gen Paul "PJ" Johnson (Ret.) and our project action officer, Maj Andre "Vader" Walton, on this project. We received helpful feedback during the course of this project from numerous individuals at the Air Force Cost Analysis Agency. We also appreciate the feedback and support of colleagues at the RAND Corporation, including Mark Arena, Frank Camm, Michael Kennedy, Chris Mouton, Dan Norton, Jia Xu, and Laura Baldwin.

Abbreviations

AUFC	average unit flyaway cost
CER	cost-estimating relationship
FY	fiscal year
ISR	intelligence, surveillance, and reconnaissance
RPA	remotely piloted aircraft

CHAPTER ONE

Introduction

Over the past decade, remotely piloted aircraft (RPA) systems have seen increased use in global conflicts. RPA systems can carry a wide range of sensors and loiter for longer periods of time. Although RPA were initially used to support intelligence, surveillance, and reconnaissance (ISR) operations, their utility has grown over time. For example, the MQ-1B (Predator) and MQ-9A (Reaper) are armed with precision weapons that allow them to perform strike missions, as well as coordination, tracking, and reconnaissance missions. Because they do not require an onboard aircraft crew, RPA systems are often better suited than traditional manned aircraft for so-called dull, dirty, and dangerous missions. Proposed military and civilian roles for RPA systems have expanded considerably beyond such missions.

Interest in acquiring new remotely piloted capabilities is likely to continue as older ISR platforms are replaced and new mission requirements are developed. At the same time, manned-aircraft designs continue to advance and are expected to remain the dominant alternative for many mission areas. Where manned aircraft and RPA are competitive alternatives, the U.S. Air Force would benefit from a better understanding of the life-cycle cost implications of each.

To better understand whether RPA systems are inherently more or less expensive to procure than manned aircraft, we compiled flyaway costs for 30 different military fixed-wing aircraft, five of which are remotely piloted (MQ-1B, MQ-1C, MQ-9, RQ-4, MQ-4C). Using these data, we developed cost-estimating relationships (CERs) that control for various aircraft characteristics, including the aircraft's empty

weight, mission area, the presence of stealth capabilities, and whether the aircraft is manned or remotely piloted. The CERs can be used for future cost and cost-effectiveness assessments that involve manned aircraft and RPA systems that might be procured in the future.

CHAPTER TWO

Data and Methodology

Manned aircraft and RPA have many similarities. For example, both air vehicles include an airframe, a propulsion system, avionics, and payload accommodations. However, manned aircraft and RPA systems also can differ in important ways. For manned aircraft, an onboard cockpit, including a display/control interface, life support systems, and an escape system, must be developed (none of which are required on RPA systems). There are also canopy and field-of-view or line-of-sight considerations that can drive design requirements. These requirements tend to add weight to manned aircraft, potentially increasing propulsion and fuel requirements. Assigning costs to these additional requirements is difficult, and these costs likely vary significantly with design specifications of the manned aircraft considered.

RPA have their own unique systems and system requirements, which can affect their acquisition costs. Most notably, ground control stations, which essentially replace the onboard cockpit, must be designed to support piloting and sensor operations. RPA require data links that are not necessary for piloting manned systems.[1] RPA might also depend on additional software for piloting (over what may be required for manned aircraft). Finally, the RPA vehicle must be treated as an interconnected system with the ground control station and

[1] It should be noted, however, that the bandwidth and data transfer requirements necessary to support piloting of the aircraft are generally small compared with those needed to support transmission of sensor data for ISR purposes. That is, manned aircraft involved in ISR missions will utilize significant communication resources, although those resources are not explicitly required for piloting the aircraft.

communication links. This can necessitate system-integration efforts beyond those required for manned aircraft (Austin, 2010).

The cost of these systems is likely to drive differences in development, investment, and operating and support costs, although disentangling their exact contribution to existing platforms is often difficult. To empirically investigate the acquisition cost implications of these issues, we compiled data for 30 different military fixed-wing aircraft, five of which are remotely piloted. Table 2.1 summarizes the aircraft in our assessment and their characteristics.

Because the unit cost of producing aircraft tends to decline with cumulative production, we normalize for the number of units produced when comparing costs across aircraft platforms. The average unit flyaway cost (AUFC) reported in Table 2.1 represents our estimate for producing the first 100 units of each platform. The cost estimates are extrapolated from cost improvement curves estimated from

Table 2.1
Summary of 30 U.S. Military Aircraft Platforms Considered in this Analysis

Platform	Manned or RP	Mission Area	Stealth	Empty Weight (pounds)	Estimated AUFC of First 100 Units (Millions of FY 2014 $s)
A-10	Manned	Fighter	No	21,379	$17.5
AV-8B	Manned	Fighter	No	14,000	$43.4
B-1B	Manned	Bomber	No	181,804	$374.4
B-2	Manned	Bomber	Yes	152,166	$1,134.3
C-17	Manned	Mobility	No	273,380	$353.6
C-2A	Manned	Mobility	No	34,400	$28.5
C-5B	Manned	Mobility	No	363,292	$180.3
E-2C (Rep)	Manned	ISR	No	40,653	$92.3
E-2C	Manned	ISR	No	40,653	$64.6
E-2D	Manned	ISR	No	42,075	$166.0
E-3	Manned	ISR	No	170,996	$153.6

Table 2.1—Continued

Platform	Manned or RP	Mission Area	Stealth	Empty Weight (pounds)	Estimated AUFC of First 100 Units (Millions of FY 2014 $s)
E-8	Manned	ISR	No	172,157	$309.5
F-14	Manned	Fighter	No	38,354	$66.1
F-15	Manned	Fighter	No	26,256	$42.8
F-16	Manned	Fighter	No	15,120	$22.4
F-22	Manned	Fighter	Yes	43,003	$217.1
F-35	Manned	Fighter	Yes	30,875	$185.2
F/A-18A/B	Manned	Fighter	No	22,459	$62.7
F/A-18E/F	Manned	Fighter	No	30,564	$112.6
KC-46A	Manned	Mobility	No	181,600	$159.2
MC-12	Manned	ISR	No	12,500	$20.0
MQ-1B	RP	ISR	No	1,130	$9.9
MQ-1C	RP	ISR	No	2,906	$10.4
MQ-4C	RP	ISR	No	15,000	$91.1
MQ-9A	RP	ISR	No	2,223	$14.5
P-3C	Manned	ISR	No	67,281	$43.5
P-8A	Manned	ISR	No	138,300	$175.2
RQ-4	RP	ISR	No	11,750	$100.0
S-3A	Manned	ISR	No	27,306	$173.9
V-22	Manned	Mobility	No	33,140	$104.9

SOURCES: Selected Acquisition Reports, the president's budget submissions (U.S. Air Force, Financial Management and Comptroller, undated), and other open sources available in 2015.

NOTE: FY = fiscal year; RP = remotely piloted; Rep = Reproduction.

annual cost and quantity information compiled for each program from Selected Acquisition Reports and other sources.[2]

Prior analyses have noted a proportional relationship between military aircraft procurement costs and empty weight (Levenson et al., 1972; Large, Campbell, and Cates, 1976; Hess and Romanoff, 1987; Younossi, Kennedy, and Graser, 2001). Figure 2.1 plots this relationship for the 30 military aircraft in Table 2.1 after applying logarithmic scaling. We obtained the fitted line and 90-percent confidence band using regression analysis for the 25 manned aircraft systems in our data set.

A few noteworthy findings are apparent in Figure 2.1. First, the proportional relationship between empty weight and cost appears to hold for our sample. Our regression equation for manned aircraft suggests that the point elasticity of flyaway cost with respect to empty weight is 0.75—indicating that, for every 10-percent increase in empty weight, AUFC for the first 100 units would increase by approximately 7 percent. Second, although RPA tend to have a much lower empty weight than the manned platforms in our sample, the relationship between empty weight and flyaway cost also holds for remotely piloted systems. The results for the MQ-1B, MQ-9A, and MQ-1C are all very close to the fitted line derived from manned aircraft data. The RQ-4 and MQ-4C estimates are somewhat above the fitted line but well within the 90-percent confidence band. From Figure 2.1, one would conclude that much of the difference between RPA and manned aircraft in cost is attributable to empty weight of the aircraft. The absence of onboard crew allows RPA to be built smaller and lighter than manned aircraft alternatives, particularly for compact and light payloads, which can yield cost savings in the form of lower flyaway costs. It could also reduce fuel costs over the aircraft's operational life.

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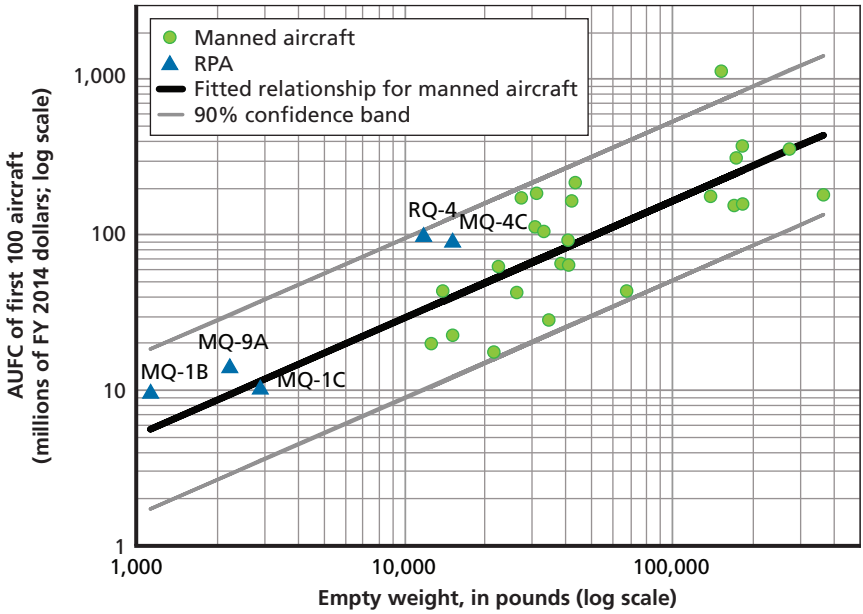
[2] Selected Acquisition Reports are status reports to Congress on the cost, schedule, and performance of Major Defense Acquisition Programs. They are generally submitted annually and during major program milestones. Other sources of information include the President's Budget submissions, Air Force fact sheets, and open source materials published by weapon system manufacturers. This information was compiled during the beginning of calendar year 2015.

Figure 2.1
Relationship Between Aircraft Empty Weight and AUFC



CHAPTER THREE

Regression Analysis

The assessment shown in Figure 2.1 is somewhat simplistic. Variables other than empty weight can influence flyaway costs. To formally test whether RPA are more or less expensive than similar manned aircraft platforms, we employ multiple-regression analyses. Specifically, we run regressions of the form

$$\log\left(AUFC_i\right) = \alpha \cdot RPA_i + \beta \cdot X_i + \varepsilon_i$$

where i is an index on aircraft systems, $AUFC_i$ is our estimate of the AUFC of producing the first 100 units of aircraft i, RPA_i is an indicator that equals 1 if platform i is an RPA system and 0 if it is a manned system,[1] X_i is a vector of aircraft characteristics that we allow to vary in different specifications, α and β are parameters to be estimated, and ε_i is a standard regression residual term.[2]

In our analysis, we run five different specifications that include various combinations of covariates in the X_i term. The covariates include empty weight, an indicator for whether the aircraft is stealthy, the rate at which aircraft were produced (measured as the average number of aircraft produced per year), the year of first aircraft delivery (so as to capture increasing technological progress and sophistication

[1] A 0 or 1 indicator is often referred to as a dummy variable.

[2] This regression form is also described as a parametric cost model or cost-estimating relationship, where cost is the dependent variable and empty weight and other features of the aircraft acquisition or design can be the independent variables (Fisher, 1970).

over time), and the aircraft's primary mission area (i.e., bomber, fighter, mobility, ISR).

The size and statistical significance of the coefficient α is our primary interest. It indicates the degree by which RPA cost more or less than manned aircraft, after controlling for other aircraft characteristics. Table 3.1 reports the regression estimates for five different regression specifications that vary in the number of control variables.

In Table 3.1, the coefficient on the RPA dummy variable (α) is positive and statistically significant in only one of our five regression equations. Other factors, such as whether the aircraft is stealthy and the rate at which the first 100 aircraft are produced, have a more predictable effect on flyaway cost than whether the aircraft is manned or remotely piloted. For example, our equations show that stealth aircraft, on average, cost between 2.1 *[= exp(0.747)/exp(0)]* and 3.8 *[= exp(1.327)/exp(0)]* times more than non-stealth aircraft with other similar characteristics. Similarly, a 10-percent increase in the production rate (e.g., increasing the number of aircraft produced from ten to 11 aircraft per year) will reduce the AUFC for the first 100 units by 2 percent to 3 percent. In our equations, the year of first aircraft delivery and mission type are not statistically significant.[3]

For an additional sensitivity analysis, we ran the same set of regressions using average procurement unit cost[4] (instead of AUFC) for the first 100 units as the dependent variable. In those regressions, the RPA variable is positive but not statistically significant at the 90-percent level in any of the regression specifications, further supporting our findings.

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[3] Mission type is not statistically significant based on an F-test performed on the set of mission-type variables.

[4] AUFCs will be lower than average unit procurement costs, because AUFCs do not include costs associated with spares or initial support services, which are paid for with procurement dollars. Analysis of flyaway costs might more accurately reflect the inherent cost of the aircraft than the average unit procurement cost because initial spare and support costs can vary with the sustainment approach adopted for a platform.

Table 3.1
Regression Results Testing for Differences in AUFC of Manned Aircraft and RPA

Specification	(1)	(2)	(3)	(4)	(5)
Intercept	–4.049***	–4.065***	–2.102	–3.997	–13.123
	(1.400)	(1.134)	(1.527)	(17.319)	(17.203)
RPA dummy (α)	0.698	0.803**	0.389	0.377	0.299
	(0.467)	(0.379)	(0.429)	(0.451)	(0.464)
Log(empty weight)	0.778***	0.785***	0.668***	0.669***	0.651***
	(0.128)	(0.104)	(0.118)	(0.121)	(0.135)
Stealth dummy		1.327***	1.262***	1.254***	0.747*
		(0.341)	(0.328)	(0.344)	(0.411)
Log(production rate)			–0.250*	–0.244	–0.345*
			(0.137)	(0.150)	(0.177)
Year of first delivery				–0.001	0.006
				(0.009)	(0.008)
Mission Type (ISR is excluded category)					
Bomber					0.906*
					(0.498)
Mobility					–0.200
					(0.316)
Fighter					0.339
					(0.350)
Observations	30	30	30	30	30
Root MSE	0.671	0.554	0.530	0.541	0.517
R-squared	0.683	0.793	0.817	0.817	0.854

NOTE: Dependent Variable = Log(AUFC for first 100 units); standard errors presented in parentheses; * = > 90% statistical significance; ** = > 95% statistical significance; *** = > 99% statistical significance; MSE = mean squared error.

CHAPTER FOUR

Conclusions

The absence of an onboard crew allows RPA to be built smaller and lighter than manned aircraft alternatives, particularly for compact and light payloads. Although RPA platforms can have a much lower empty weight than any of the manned platforms in our sample, we find the RPA flyaway costs tend to follow the same relationship with respect to empty weight as the manned aircraft. We conclude that the family of RPA included in this analysis is not considerably different from manned aircraft from a flyaway cost perspective, with much of the difference in cost across platforms explained by the empty weight of the aircraft.[1] However, the absence of onboard crew allows RPA to be built smaller and lighter than manned aircraft alternatives, particularly for compact and light payloads, which can result in cost savings (reduced flyaway costs).[2]

Factors besides empty weight correlate strongly with flyaway costs. For example, stealth aircraft cost between 2.1 and 3.8 times more than non-stealth aircraft with other similar characteristics. We also find that the rate at which aircraft are produced has a meaningful impact on

[1] We conducted further analysis to control for other factors affecting flyaway costs, such as whether the aircraft is stealthy, the number of aircraft procured per year, the year of first delivery, and the aircraft mission area (i.e., bomber, fighter, mobility, or ISR). Our statistical findings suggest that the unit flyaway costs of military RPAs are not statistically different from those observed for manned military aircraft after controlling for other factors. Factors besides empty weight that correlate strongly with flyaway costs include the incorporation of stealth technology into the aircraft design and the number of aircraft produced per year.

[2] The lower empty weight of RPA aircraft should also reduce fuel costs over the aircraft's operational life cycle.

flyaway costs, with a 10-percent increase in the production rate reducing the AUFC for the first 100 units by 2 percent to 3 percent.

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