Accommodating Difference: Gender and Cockpit Design in Military and Civilian Aviation

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Primarily on the basis of interviews, the treatment of gender is compared as a human factors consideration within military and civilian aviation. Defense and civilian cockpits have traditionally been built to specifications based on male anthropometry and may embody a physical bias against women and smaller-statured men. Defense and commercial divisions of airframe manufacturers rely on similar computer modeling techniques and anthropometric data to accommodate a targeted population of pilots. However, the design of defense aircraft tends to be highly regulated, and more efforts have been taken to ensure that a larger pool of otherwise eligible pilots is accommodated by future systems, such as in the Joint Primary Aircraft Training System. Within very loose FAA guidelines, commercial manufacturers are responsive to their customer airlines, most of which are not concerned with accommodating women pilots unless they fear liability for employment discrimination. Commercial manufacturers also do not possess adequate anthropometric data about the civilian female pilot population. Because of defense budget cutbacks, a changing social context, and a broader political mandate, the public sector has a responsibility both to facilitate the transfer of knowledge from military to civilian aviation and to concern itself with the equity issues involved in accommodating female pilots.

To examine issues concerning women and technology, social scientists commonly rely on two approaches (*1*). The first approach questions women's access to particular technologies. In the context of aviation, one would ask questions regarding women's upward mobility in the profession; for example, are women limited because they are not trained, socialized, or permitted to fly certain aircraft? Solutions to these problems would lie in eroding barriers to these boundary markers, such as easing women-in-combat exclusions or providing scholarships for women to attend flight training school.

The second approach—which informs the subject of this paper—questions the technology itself. Are cockpits designed to accommodate women's bodies? Is a particular flight deck "gender neutral" or is male bias embodied in the actual design, in the engineering specifications? How can biased technologies be altered to become more "women friendly"?

Such questions are receiving attention within the military as human factors practitioners at the Pentagon attempt to determine whether the Joint Primary Aircraft Training System (JPATS), the primary aircraft trainer used by the Navy and Air Force, embodies a bias against women and smaller-statured pilots. After successful completion of mandatory JPATS training, student pilots advance to intermediate trainers and then to aircraft-specific training. Therefore, if women cannot "fit" into the JPATS cockpit or if the cockpit does not "fit" women pilots, they will be unable to pursue aviation careers in the Navy or Air Force. Other defense aircraft as well as ships and protective clothing are also receiving such scrutiny (*2*).

Human factors work conducted in the military has significant ramifications for civilian aviation. For example, limits on participation by women in military flying roles may inhibit career prospects in civilian aviation since many airlines still prefer pilots with military training. Civilian aircraft may also embody similar biases against women's bodies because they have been designed for a primarily male pilot population. Because of the significance of these man-machine systems, this paper will examine the treatment of gender as a human factors consideration within military and civilian aviation. It will outline the methods used by the military to determine whether cockpits are women friendly and compare these methods with research conducted on this human factors issue in civilian aviation.

Because there is a dearth of literature in this area, this paper relies heavily on interview studies and the interpretation of internal documents. Interviews were conducted with human factors specialists at major airframe manufacturers, public-sector research laboratories, and regulatory agencies. Qualitative research, compared with more empirical policy analysis, allows one to engage the ideological assumptions embedded within the policy debates. Such an approach seeks not only to understand the effects of technological change on society but also to ask which social factors have shaped technological change.

BIAS IN DEFENSE AIRCRAFT

Defense systems have traditionally been built to male specifications (*3*). Since women tend to be shorter and have smaller limbs and less upper-body strength, some may not be accommodated by such systems and may experience difficulty in reaching controls and operating some types of equipment (*4*). To understand how women's bodies become excluded by design, it is necessary to examine how current weapon systems are designed with regard to the physical differences of their human operators.

The best technology is useless if it is incompatible with the capabilities and limitations of its users. As such, Department of Defense acquisition policy mandates that human considerations be integrated into design efforts to improve total system performance by focusing attention on the capabilities and limitations of the human operator.

To integrate the soldier, sailor, and airman into current design practices, the military relies on human factors theories, also called "human engineering" or "ergonomics," which address human characteristics, expectations, and behaviors in the design of items that

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people use. During World War II, human factors became practiced as a distinct discipline by the U.S. military when it became apparent that new and more complicated types of military equipment could not be operated safely or effectively and could not be maintained adequately by many well-trained personnel (*5*). An effort was directed to design equipment that would be more suitable for human anthropometry.

Anthropometrics refers to the measurement of dimensions and physical characteristics of the body as it occupies space, moves, and applies energy to physical objects as a function of age, sex, occupation, ethnic origin, and other demographic variables. The military has routinely measured and categorized different body dimensions to standardize the design of weapons systems. The U.S. Army Natick Research Development and Engineering Center "1988 Anthropometric Survey of Army Personnel" is the most recent compilation of these data. The Natick Survey contains data on more than 180 body and head dimension measurements of a population of more than 9,000 soldiers. Age and race distributions match those of the June 1988 active duty Army, and minority groups were intentionally oversampled to accommodate anticipated demographic shifts in Army population.

In the application of anthropometric data, systems designers rely on Military Standard 1472, Human Engineering Design Criteria for Military Systems, Equipment and Facilities. As with the use of military specifications in defense procurement, these guidelines are critical to developing standards that reflect the military's needs and goals and are ultimately embodied in the technology. These guidelines suggest the use of 95th and 5th percentile male dimensions in designing weapons systems, if the accommodation of 100 percent would incur trade-off costs out of proportion to the additional benefits to be derived. However, determining what is a "trade-off cost" and when such costs are too high can be an arbitrary process.

Accommodation becomes more difficult when more than one physical dimension is involved, and several dimensions need to be considered in combination. Difficulties arise from the interrelationships between and among the dimensions, some of which have low correlations with each other (e.g., sitting height and arm length). For example, in military applications approximately 52 percent of Navy aviators would not be accommodated by a particular cockpit specification if both the 5th and 95th percentiles were used for each of the 13 dimensions. To determine whether operators of different shapes and sizes can be accommodated in weapons systems, human factors specialists rely on advanced two- and three-dimensional modeling techniques. However, the changing anthropometry of the military population has not altered the tools available to determine female accommodation; the Air Force, for example, does not possess female mannequins, choosing instead to cut the arms of male dummies.

Because women are often smaller in all physical dimensions than men, the gap between a 5th percentile woman and the 95th percentile male can be very large. Women who do not meet requirements are deemed ineligible to use a variety of military systems. Before the operating requirements became so stringent, women pilots adapted their bodies to the technology. They mounted wooden blocks on the bottoms of their boots to reach the rudder pedals of the T-37 and used pads on their seats.

In the case of the JPATS trainer, minimum anthropometric requirements needed to effectively operate such an aircraft were considered, and specifications were written to reflect such requirements. For example, "the ability to reach and operate leg and hand controls, see cockpit gauges and displays, and acquire external vision required for safe operation" was considered critical to the safe and efficient operation of the system. The five critical anthropometry design "drivers" were determined to be sitting height, functional arm reach, leg length, buttock-knee length, and weight (JPATS Cockpit Accommodation Working Group Report, May 1993, unpublished data).

Original JPATS specifications included a 34-in. minimum sitting height requirement to safely operate cockpit controls and eject. This specification was based on sitting height minimums in the current aircraft fleet and reflected a 5th percentile male standard. However, at 34 in., anywhere from 50 to 65 percent of the American female population is excluded because female sitting heights are generally shorter than those of males. Therefore JPATS, as originally intended, accommodated the 5th through 95th percentile male but only approximately the 65th through 95th percentile female.

NEGOTIATING ACCOMMODATION IN THE MILITARY

When former Secretary of Defense Les Aspin announced the administration's policy on women in combat in April 1993, he sought to implement a congressional mandate that would permit women to compete for all assignments in aircraft, including those aircraft engaged in combat missions. Although the new policy gave women a greater combat aviation role and was intended to permit their entry into many new assignments, the aircraft associated with the new assignments precluded the directive from being implemented. That existing systems could contain a technological bias against women's bodies despite the congressional mandate for accessibility alarmed policy specialists at the Pentagon. This contradiction would potentially embarrass a new administration, which was caught off guard with the gays-in-the-military debacle and was trying to define a working relationship with an antagonistic Pentagon.

Instead of fitting the man to the machine as was the norm, it was seen to be necessary to fit the machine to the (wo)man. Stipulating new operational requirements of users would also entail changing the technology. In May 1993, the Under Secretary of Defense (Acquisition) directed the Assistant Secretary of Defense (Personnel and Readiness) to develop a new sitting height threshold that would accommodate at least 80 percent of eligible women. He delayed release of the JPATS draft request for proposal until a new threshold could be documented.

This move led to the development of the JPATS Cockpit Accommodation Working Group within the Pentagon, which included representatives from the Air Force and Navy JPATS program offices as well as from service acquisition, personnel, human factors, and flight surgeon organizations. After months of deliberation, the working group determined that a reduction of the sitting height requirement by 3 in. would accommodate approximately 82 percent of women (JPATS Cockpit Accommodation Working Group Report, May 1993, unpublished data).

Reducing the envelope to 31 in. would require significant cockpit modifications, largely because ejection equipment significantly restricts the ability to adjust the seat. In addition, there was the possibility that the aircraft nose, rudder, and other flight controls would also need to be substantially modified to accommodate a smaller person. Further, since ejections at smaller statures and corresponding body weights have yet to be certified for safety, test articles and demonstrators would need to be developed to ensure safe ejection

(E. Dorn, Memorandum on JPATS Cockpit Accommodation Working Group Report, Oct. 19, 1993, unpublished data).

As debates continued in the press and within the working group during 1993, the possibilities for technological variety began to close down. In the JPATS case, administrative closure was achieved when the 1994 Defense Authorization Bill was passed. The bill included a provision preventing the Air Force, the lead agency in the purchase of the JPATS, from spending $40 million of a $41.6 million trainer budget unless the Pentagon altered the cockpit design (*6*). John Deutch, then the Under Secretary of Defense, wrote in a memorandum legitimizing the problem of accommodation of women in defense aircraft:

> I believe the Office of the Secretary of Defense (OSD) should continue to take the lead in addressing this problem. Other platforms in addition to aircraft should be considered as well. We must determine what changes are practical and cost effective in support of SECDEF policy to expand combat roles for females. I request that you take the lead in determining specification needs. Further, you should determine the impact of defense platforms already in production and inventory. (J. Deutch, JPATS Cockpit Accommodation Working Group Report, Dec. 2, 1992, unpublished data)

The impetus for changing the sitting height requirement and the JPATS itself arguably came directly from Congress and the president. However, this assertion does not discount the contributions made by several organizations within the Pentagon and the services, which, cognizant of the bias inherent in defense aircraft, were exploring alternatives to such technologies. For example, the Human Systems Integration (HSI) departments in the Office of the Secretary of Defense have consistently focused on integrating human factors into the preacquisition process of weapons procurement. Pentagon acquisition policy requires program managers during the acquisition phase to document what human system risks exist in predecessor or comparable systems, what studies and analyses are planned to identify or mitigate human risks, and the status of these efforts before each milestone decision review. Subsequently, HSI submits its assessments to the Defense Acquisition Board. It is through this process that the lack of accommodation of women by JPATS and design flaws inherent in other systems have been raised for senior-level deliberation and resolution before the systems have gone into actual production.

RELATIONSHIP BETWEEN HUMAN FACTORS IN MILITARY AND CIVIL AVIATION

The synergy between national security needs and civil aviation—both aircraft manufacturers and air transport—has been well documented. Military objectives shaped the American aircraft industry; indeed, the structure of the industry today is a consequence of earlier government procurement policies (*7*). Military-funded research and development, particularly in propulsion technology, has benefited commercial aircraft. Many of the earlier civilian airplanes were converted from military aircraft. On the other hand, technology developed for commercial requirements has had significant military applications, including such examples as the CF6 turbofan engine, flight-management systems, and improved fuel efficiency. In addition, the civil transport system is often perceived as a reserve military fleet in the event of a wartime emergency (e.g., during Operation Desert Storm).

As such, much of the technology base, supplier base, skills, and processes used by defense and civil aircraft are held in common. The principal commercial airframe producers all rely on substantial military sales. Often the divisions responsible for military and civilian work are physically and organizationally separate, but a high degree of labor mobility and technology exchange may exist.

Since World War II, the military has traditionally taken the lead in human factors research. Indeed, the field developed as attention was given to the "knob and dial" types of problems associated with designing control devices and visual instruments that could be used more rapidly and accurately. The range of operating requirements and the need to understand the characteristics of the user population before acquisition led the services to begin collecting and classifying data about the military population (*8*). Today, the Army's Natick Research and Development Command and the Air Force Systems Command's Human Systems Division at Wright-Patterson Air Force Base in Ohio still provide the most accurate anthropometric data.

Those in civilian aviation are considered to lag behind their military colleagues in the general field of human factors research. With specific regard to the accommodation of female pilots, many believe that the military has taken the lead in evaluating (wo)man-machine interaction. Located at the intersection of technology, economics, and labor relations, the issue of female accommodation in the private sector has been framed in a very different manner.

ACCOMMODATING WOMEN IN COMMERCIAL AIRCRAFT

Manufacturers are unsure of the total population of women commercial pilots, let alone their body dimensions. The number of women earning their air transport rating in the United States has increased by 325 percent since 1980. However, the percentage of women pilots is still approximately 3 in the United States and significantly lower worldwide (*9*). The FAA Statistics and Forecast Branch maintains information on the number of women pilots who have a current medical certificate and a pilot license. In 1993, 39,460 women held both the certificate and license out of a total of 665,069 pilots (*10*). However, these figures do not reflect the number of women actually employed as commercial pilots. In 1990, the Air Line Pilots Association stated that there were approximately 900 women pilots (out of a total of 43,000) at 44 of the airlines where it had members at that time.

Despite their similar origins, the cockpit technology encountered in civilian aviation differs substantially from that found in the military. The function that the human being is intended to perform and the types of mechanisms provided for him or her in the control processes also differ. For example, the extreme rates of acceleration experienced in military cockpits require elaborate restraining devices. Such restraints must be designed for the anthropometric characteristics of the intended users. The main complaints with the JPATS center on ejection seats and the need to provide safe ejection to lighter individuals.

In contrast, commercial aircraft do not reach the same high speeds as military planes, nor do they contain ejection seats. The seats in a commercial cockpit are adjustable to meet the varied comfort and safety requirements of the users. Thus, certain characteristics, such as height, weight, and strength, do not have the same valence in commercial aviation as they do in the military. Many argue that commercial aircraft can accommodate a more variable population because the operating requirements are not as stringent as in the military.

The location of various controls on the commercial flight deck, however, may disadvantage women and smaller-statured men. Although the seats are more adjustable, individuals with smaller functional arm reach and less upper-body strength may still experience difficulties manipulating controls. When women are sitting on the left, some complain that they cannot reach controls on the right side. Although electrical and hydraulic systems require smaller forces to actuate, reach concerns become increasingly important during manual reversion.

Major airframe manufacturers have integrated human factors as part of their initial concept and design process and have designed flight decks for both men and women pilots since the early 1980s. The methods that human factors practitioners in the commercial world use to determine accommodation are quite similar to those used by the military, many having been developed by internal defense divisions or borrowed directly from the public-sector research laboratories. Contractors experiment with various computerized human modeling packages (i.e., CATEA, GENECONN, CREW CHIEF, COMBIMAN) during the preliminary design stages. With the use of such programs—most of which run in conjunction with computer-aided design systems—engineers are able to analyze visibility and reach in a proposed cockpit design. Such programs create three-dimensional graphic representations of pilots that can be adjusted to different body sizes and proportions on the basis of accumulated anthropometric data from the Army surveys. Since the Army data contain both male and female standards, the various programs do not differ significantly in their ability to model women. However, cockpits are generally designed for a population with a range of 25th percentile military women to 99th percentile military men.

Although military and commercial engineers use similar methods and data, the pilot populations may differ. In other words, the fact that commercial aviation relies on anthropometric data representative only of military populations could pose a problem. Many agree that at present the largest obstacle in overcoming design bias against women pilots is the lack of comprehensive anthropometric data for civilian female populations.

The only available civilian data are very old. For female measurements, some manufacturers still use a 1940 Department of Agriculture survey conducted for clothing dimensions. These data are not extensive enough for use in designing large, complex interfaces, such as cockpits. Conducting a survey of civilian pilots would be expensive and time consuming; it appears that no one financially strapped airline company is willing or able to undertake such a project now.

Human systems specialists suspect that more variability exists in the civilian pilot population because civilian airlines have less restrictive eligibility requirements and a more expansive age range than the military. For example, commercial airlines do not maintain the same limits on body weight and height. In the military, most pilots are between 21 and 35 years old, whereas commercial airlines employ an older population, primarily former servicemen. In the past, commercial pilots received their training in the military, whereas now the trend is to filter through private flight-training schools. This results in a less standardized commercial pilot population, one that might not be represented in the anthropometric data culled by the military.

Once the cockpit design moves to the production stage, manufacturers rely on a working group of active pilots in their mock-up studies and verification analyses. Boeing chooses men and women of different shapes and sizes and asks them to reach to the extremes of the cockpit. McDonnell Douglas interviews the pilots themselves as well as their union to get feedback about accommodation. Distinguishing between comfort and accommodation is one of the main problems facing human factors practitioners. Comfort problems might include backaches, circulation problems, wear spots on elbows, and inadequate room for legs in contrast to accommodation concerns, such as the ability to fully see and perform necessary pedal work.

The process of designing and developing a cockpit is different for each manufacturer and for each aircraft. Because commercial airframe manufacturers design for many different customers, they must incorporate the preferences of each individual customer airline into their designs. Unlike defense contracts, the only regulations that standardize the design of the cockpit with respect to human factors come from FAA and are found in FAR Part 25.777C:

> The controls must be located and arranged with respect to the pilot seats so that there is full and unrestricted movement of each control without interference from the cockpit structure or the clothing of the minimum flight crew (established under 25.1523) when any member of this flight crew from 5′2″ to 6′3″ in height is seated with the seat belt and shoulder harness (if provided) fastened.

The regulations make no mention of the gender of the intended user but manufacturers interpret them to include both male and female pilots.

Many believe that the FAA guidelines are limited by their lack of enforcement and by their ambiguity—for example, height may not be the sole design driver or determinant of accommodation. Nonetheless, manufacturers are required to write a report, complete with mock-ups and models, stating that the design complies with FAA physical requirements. However, FAA is often unable to verify that smaller pilots would be accommodated because it is attending to other more critical design issues.

Manufacturers are responsive to their carrier customers within the FAA guidelines; they consider the accommodation of women and smaller-statured people in any design, but just how much of an issue it becomes—how big the envelope, how adjustable the seat—is based on the particular customer's preference. Few customer airlines are concerned with accommodating women pilots specifically, but some have made queries pertaining to height requirements and other human factors issues. The European airlines tend, on the average, to be more savvy about human-machine interface and ergonomics. For example, KLM has sophisticated human factors capabilities and is known for considering the "social" impacts of design. Whether one can attribute this sensitivity to the relative strength of unions or to the traditions of social democracy is open for debate.

Domestic airlines may inquire about physical stature in the context of labor relations. Manufacturers are occasionally contacted by the carriers' legal departments, which fear that the airlines will be sued for employment discrimination because height and strength requirements for pilots are so high as to exclude a significant number of women. For example, a woman pilot trainee who failed a simulator test might claim that the airline, and the aircraft itself, are biased against those with less upper-body strength. The airlines fear that they will be unable to justify such requirements as bona fide occupational qualifications critically related to job performance. Airlines have contacted private anthropometric consultants to help redefine height criteria to avoid allegations of sex discrimination.

Airframe manufacturers are also sensitive to the perception that as the ethnic and racial makeup of the nation changes, the accommodation of smaller men will become increasingly necessary. In addition, the prospect of foreign sales, both military and commercial, to countries with different-sized populations makes accommodation an important economic consideration. In the first paragraph of a memorandum to the Under Secretary of Defense (Acquisition), Assistant Secretary of Defense Edwin Dorn stressed that

> a reduced JPATS sitting height threshold will also expand accommodation of shorter males who may have previously been excluded from pilot training. For potential foreign military sales, this enhances its marketability in countries where pilot populations are of smaller average stature. (E. Dorn, Memorandum on JPATS Cockpit Accommodation Working Group Report, Oct. 19, 1993, unpublished data)

However, most foreign countries—excluding those of Western Europe—are not concerned with these types of human factors issues and rarely inquire about cockpit accommodation. In addition, international anthropometric data are very difficult to compile or access. Foreign militaries, often the repositories of such data, are hesitant to release their information for national security reasons.

Those airframe manufacturers who also build defense aircraft have been sensitized to the issue of accommodation in commercial planes. Government contracts are much more specific in their design requirements and are beginning to specify the need for the accommodation of women. Contractors try to stay one step ahead of the Pentagon to win their share of a decreasing number of procurements. For example, McDonnell Douglas has been an advocate of female accommodation for years because it foresaw that the women-in-combat exclusion would eventually be eliminated. Its human factors division invested heavily in human factors research to be better positioned to win government contracts.

CONCLUSION

Some argue that the issue of design accommodation is not about women but about the ways in which aircraft have evolved over the past 80 years. Most of the current inventory was designed before women had entered the profession. As Reppy (*11*) notes, "Closure in the design of these [technologies] ha[d] been reached in a time and context in which the idea of women as potential users was not considered; in effect, the current technologies were born gendered." A cycle was created whereby an older population of predominantly male pilots defined the design of new aircraft, which, in turn, defined the operational requirements for new pilots. The new generation of pilots—women included—must distinguish between legitimate operational requirements instituted for safety and efficiency purposes and the residue of male bias from decades as a single-sex profession.

Others argue that design accommodation is not a gender issue, but one solely concerned with size and stature. Physical systems and accoutrements cannot be designed for the typical human because humans come in different shapes and sizes. Smaller-statured individuals—male and female—are discriminated against in design, but women, who are smaller on the average, tend to suffer disproportionately. Men's and women's bodies are biologically different, but women must "pass" as men to have legitimate claim to certain professions and technologies. Women pilots are left with a quandary: do they prove that they can meet male standards or do they work to change the standards and the technology because the standards tend to disproportionately exclude women?

As airlines downsize and the competition for pilot positions increases, few women or smaller-statured pilots are likely to complain about any perceived lack of accommodation and demand special treatment. Private airframe manufacturers are accountable to their airline customers, many of whom either are not concerned about this issue or do not receive sufficient input from their line pilots. Customers have traditionally been more concerned with profit or payload motives, such as the number of passenger seats and cargo capacity, than with cockpit requirements (*12*). In addition, there is speculation that the JPATS project will be delayed indefinitely or abandoned because of budgetary constraints.

The civilian public sector may be the proper channel through which issues of design accommodation can be addressed and regulated. An editorial in *Aviation Week and Space Technology* (March 30, 1992) claims that "only the federal government is likely to pursue the high-risk type of basic research that is needed to keep the aerospace industry on the forefront of human factors knowledge." Such research at FAA and NASA is funded at only approximately $45 million per year despite 65 percent of air transport accidents being attributable to human factors and flight crew error.

In the absence of other initiatives, it may be the role of FAA not only to investigate the potentially discriminating effects that design may have on women's opportunities in the pilot profession but also to facilitate the transfer of knowledge from military to commercial sectors in this area (*13*). Design accommodation of women offers tremendous opportunity for technology transfer to civilian transportation because the military, with its stringent specifications, sensitizes engineers to the inclusion of women in design. Often this kind of transfer occurs internally between the commercial and defense divisions within the same company. Individuals who work on both sides encourage a cross talk in techniques and expertise.

However, more public-sector involvement in creating effective coupling between all areas of research and development that are pertinent to both military and civil systems is warranted. The world-class capabilities of the Department of Defense laboratories need to play a key role in the strategies for human factors research in the civilian sector. Cooperative research and development agreements, which have given the laboratories a mandate to expand their ties with industry, would allow their researchers to develop consortia of airlines, airframe manufacturers, and consultants to create a more comprehensive data base of civilian dimensions. One informant suggested that such an arrangement be pursued to conduct a comprehensive collection of civilian female anthropometric data.

Whereas once federal research and development funds were allocated to enhance the capacity of high-tech weapons systems, the emphasis in the past decade has shifted somewhat to the use of human resources to maximize the efficiency of such systems. In light of defense cutbacks and changing social contexts, the public sector also needs to take a more active regulatory role in equity maximization. Regulating the accommodation of a larger pool of pilots in the concept and design phase would ensure a more equitable outcome than relegating such issues to the logic of the market and the courts.

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