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TECHNICAL REPORT

Pricing Strategies for NASA Wind-Tunnel Facilities

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RAND

INFRASTRUCTURE, SAFETY, AND ENVIRONMENT and
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Preface

In 2003, at the request of Congress and the National Aeronautics and Space Administration (NASA), the RAND Corporation undertook a yearlong study of the 31 wind-tunnel and propulsion test facilities at three NASA centers (see *Wind Tunnel and Propulsion Test Facilities: An Assessment of NASA's Capabilities to Serve National Needs*, Santa Monica, Calif.: RAND Corporation, MG-178-NASA/OSD, 2004; and *Wind Tunnel and Propulsion Test Facilities: Supporting Analyses to an Assessment of NASA's Capabilities to Serve National Needs*, Santa Monica, Calif.: RAND Corporation, TR-134-NASA/OSD, 2004). The researchers examined current and future national needs for wind-tunnel and propulsion test facilities, the technical competitiveness of NASA's facilities, functional overlap and redundancy among NASA facilities, and management issues. Several years later, RAND updated its research in these areas (see *An Update of the Nation's Long-Term Strategic Needs for NASA's Aeronautics Test Facilities*, Santa Monica, Calif.: RAND Corporation, DB-553-NASA/OSTP, 2009). Since 2008, RAND has been helping NASA's Aeronautics Test Program conduct strategic planning and develop assessment tools for managing NASA's aeronautics testing enterprise. This technical report is an outgrowth of concerns, discussions, and background research related to pricing major wind-tunnel test facilities.

NASA maintains a large array of national-class aeronautics testing capabilities, but there has been an overall downward trend in the use of its wind-tunnel test facilities. Fiscal pressures have increased incentives to cut costs and create additional sources of revenue to sustain and expand the testing capabilities that NASA offers.

The objective of this report is to identify six approaches for pricing the use of NASA wind-tunnel test facilities: (1) marginal cost pricing, (2) two-part pricing with full cost recovery, (3) two-part pricing with subsidization, (4) average cost pricing, (5) average cost pricing with subsidization, and (6) no charge. Using a simple analytic framework, this report compares these pricing strategies in terms of their efficiency, their effect on NASA's budget, and their fairness. The sixth option, not charging for use, performed poorly across all criteria; the other five approaches performed well against at least one criterion.

The research presented in this technical report was funded by the NASA Aeronautics Test Program. This report should be of interest to managers and operators of government research, development, testing, and evaluation facilities that are routinely used by organizations in the private sector or by other government agencies, such as the national-class facilities found in NASA or the Department of Defense. It should also be of interest to the decisionmakers who oversee the operation and budgeting of these facilities.

The study was conducted jointly in the RAND Transportation, Space, and Technology (TST) Program within RAND Infrastructure, Safety, and Environment (ISE) and the Acquisition and Technology Policy Center, part of the RAND National Defense Research Institute.

The RAND Transportation, Space, and Technology Program

The mission of RAND Infrastructure, Safety, and Environment is to improve the development, operation, use, and protection of society's essential physical assets and natural resources and to enhance the related social assets of safety and security of individuals in transit and in their workplaces and communities. The TST research portfolio encompasses policy areas including transportation systems, space exploration, information and telecommunication technologies, nano- and biotechnologies, and other aspects of science and technology policy.

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The RAND Acquisition and Technology Policy Center

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For more information on the Acquisition and Technology Policy Center, see http://www.rand.org/nsrd/ndri/centers/atp.html or contact the director (contact information is provided on the web page).

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Summary

Evaluating Approaches for Pricing NASA Test Facilities

The National Aeronautics and Space Administration (NASA) maintains a large array of national-class aeronautics test capabilities. With the maturation of aerospace technology over the past century, the end of the Cold War, and the growing capability of computational fluid dynamics, there has been an overall downward trend in the use of NASA's wind-tunnel test facilities. At the same time, fiscal pressures have increased incentives at NASA to cut costs and create additional sources of revenue to sustain and modernize the test capabilities the organization offers.

The RAND Corporation was asked to explore the trade-offs among alternative approaches for charging users of NASA's wind-tunnel test facilities. The RAND team analyzed the following six strategies for pricing a notional test facility:

- **Marginal cost pricing (MC).** Each user is charged an hourly fee equal to the test facility's marginal operating cost.
- **Two-part pricing with full cost recovery (TPP).** Each user is charged both a fixed fee and a variable fee. The fixed fee (i.e., an annual subscription fee or test setup fee) is set to approximately balance the facility's annual budget; the variable fee equals the facility's marginal operating cost. (One could think of this approach as MC with a subscription fee.)
- **Two-part pricing with partial subsidization (TPPS).** As in TPP, each user is charged both a fixed fee and a variable fee. However, the fixed fee is set to recover only some of the facility's annual budget; NASA is expected to subsidize the rest.
- **Average cost pricing (AC).** Each user is charged a variable rate, determined annually, that is set to approximately recover all of the facility's costs.
- **Average cost pricing with partial subsidization (ACS).** As in AC, each user is charged a variable rate. However, the revenues collected cover marginal operating costs and a portion—but not all—of the facility's annual budget; NASA is expected to subsidize the rest.
- **No charge for use (NC).** Each user is granted access to the facility at no cost beyond the direct pass-through consumable costs, such as for electricity.

The team evaluated each of these approaches for pricing wind-tunnel use in terms of their ability to (1) promote efficient use of test facilities as defined by economists (i.e., efficiency), (2) generate revenue to offset costs (i.e., fiscal impact), and (3) produce a fair allocation of costs between beneficiaries (i.e., fairness). Details regarding how these metrics are defined and evaluated are documented in the report's complete economic analysis, which compares cost, benefit, and utilization levels.

The performance of each pricing approach is summarized in Table S.1. Although no strategy performs well across all three criteria, the no-charge policy stands out for performing poorly across all three criteria. Specifically, a no-charge policy would lead to overutilization of facilities from an efficiency perspective, would result in the largest budget shortfall of any of the pricing strategies we reviewed, and would perform poorly in terms of fairness because NASA would be forced to pay all costs even though users outside the agency would benefit from using NASA's test facilities.

In selecting between pricing alternatives, NASA will be forced to make trade-offs:

- Marginal cost pricing and both forms of two-part pricing perform well in terms of efficiency. The no-charge policy and both forms of average cost pricing perform moderately or poorly, but for different reasons: Both forms of average cost pricing would lead to underutilization of test facilities, and a no-charge approach would lead to overuse.
- In terms of making facilities financially self-sustaining through user charges, two-part pricing with full cost recovery and average cost pricing perform well, producing revenues in line with total costs. These pricing strategies are likely to be viewed as more attractive if the budgetary environment at NASA becomes more constrained. On the other hand, a no-charge approach not only means that NASA has to cover all costs but also that it is more likely to lead to overuse and therefore drive up costs.
- In terms of fairness, two-part pricing with subsidization and average cost pricing with subsidization are likely to be viewed as attractive options. Both forms of full cost recovery—two-part pricing and average cost pricing—perform poorly in terms of fairness because users must pay for all of a facility's fixed costs, even though a facility's availability is dictated by strategic national security considerations that are not tied to any particular user. A no-charge system performs poorly in terms of fairness because it forces NASA to pay all costs.

Table S.1
The Performance of Alternative Pricing Approaches Against the Three Criteria

Pricing Approach	Efficiency	Fiscal Impact	Fairness
Marginal cost pricing	Good	Poor	Moderate
Two-part pricing with full cost recovery	Good[a]	Good	Poor
Two-part pricing with partial subsidization	Good[a]	Moderate	Good
Average cost pricing	Moderate to poor[b]	Good	Poor
Average cost pricing with partial subsidization	Moderate	Moderate	Good
No charge	Moderate to poor[b]	Very poor	Poor

[a] The model outlined here assumes that the fixed fees imposed under a two-part pricing scheme will not discourage any potential users from participating in NASA's test facility user base. This means that both two-part pricing schemes—TPP and TPPS—perform well in terms of efficiency. This assumption may be questionable, however, and, if a two-part pricing system is pursued, it merits additional research.

[b] AC and NC policies can be less efficient than ACS because they can result in a price that is further from the marginal cost when both fixed and marginal costs are substantial. However, facilities with marginal costs approaching zero would find NC to be more efficient than ACS unless the subsidy approaches 100 percent of fixed costs. Similarly, facilities with fixed costs approaching zero would find AC to be more efficient than ACS unless the subsidy approaches zero.

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This research has benefited from helpful conversations with and feedback from Philip Antón, James Kallimani, and Johanna Zmud at RAND and Michael George and Timothy Marshall at NASA. Timothy Brennan at Resources for the Future and Jennifer Lamping at RAND provided helpful reviews that greatly improved this report.

Abbreviations

AC	average cost pricing
ACS	average cost pricing with partial subsidization
ATP	Aeronautics Test Program
BS	budget shortfall
CFD	computational fluid dynamics
CS	consumer surplus
DoD	Department of Defense
MC	marginal cost pricing
NASA	National Aeronautics and Space Administration
NC	no charge for use
R&D	research and development
T&E	testing and evaluation
TPP	two-part pricing with full cost recovery
TPPS	two-part pricing with partial subsidization

CHAPTER ONE

Introduction

The National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD) maintain a large array of national-class aeronautics test capabilities. These capabilities support both NASA and DoD projects, as well as projects pursued by the U.S. aerospace industry.[1] However, with the maturation of aerospace technology over the past century, the end of the Cold War, and the growing capability of computational fluid dynamics, there has been an overall downward trend in the use of NASA's wind-tunnel test facilities. At the same time, fiscal pressures have increased incentives at NASA to cut costs and create additional sources of revenue to sustain and modernize the test capabilities it offers.

In this report, we develop a simple economic model of the benefits and costs generated from a hypothetical wind-tunnel test facility. Two types of benefits associated with maintaining and operating the wind-tunnel test facility are considered: (1) benefits that accrue directly to users from test activities and (2) strategic national security benefits that accrue broadly to citizens from maintaining test capabilities. These benefits are compared with the cost of operating and maintaining the test facility. We categorize these costs into those that are fixed and those that vary with usage.

In all but one of the model's pricing policies, users must pay to use the test facility. These different policies affect how much testing users opt to engage in, and this in turn affects the benefits and costs associated with wind-tunnel test facilities.

We explored six alternative approaches that NASA could apply to users of its wind-tunnel test facilities: (1) marginal cost pricing, (2) two-part pricing with full cost recovery, (3) two-part pricing with subsidization, (4) average cost pricing, (5) average cost pricing with subsidization, and (6) no charge beyond a pass-through of direct consumables, such as electricity. In this report, we use a simple economic model to illustrate the effect of each these six pricing strategies in their ability to (1) promote efficient use of test facilities as defined by economists (i.e., efficiency), (2) generate revenue to offset costs (i.e., fiscal impact), and (3) produce a fair allocation of costs between beneficiaries (i.e., fairness).

The analysis clearly identifies trade-offs associated with pursuing each of the pricing alternatives we examined. If efficient utilization of test facilities is deemed most important, then marginal cost pricing is attractive. Both forms of two-part pricing (i.e., two-part pricing with full cost recovery and two-part pricing with partial subsidization) may be attractive from an efficiency perspective, but this depends on both how the fixed-fee component of the two-part pricing approach is set and how sensitive users are to this cost. If greater emphasis is placed on

[1] The Aeronautics and Space Engineering Board, National Research Council (1988) notes that NASA test facilities tend to emphasize research capabilities and that DoD test facilities are more focused on supporting production activities.

making wind tunnels financially self-sustaining, two-part pricing with full cost recovery and average cost pricing perform best. Finally, if NASA is most interested in pursuing a pricing strategy that is perceived as fairly distributing costs and benefits, two-part pricing with partial subsidization and average cost pricing with partial subsidization are most attractive. A no-charge strategy performs poorly in terms of all three of the criteria we analyzed.

In the next chapter, we present the economic framework that we used to conduct our analysis. Chapter Three provides a comparative assessment of the pricing policies within the context of the framework presented in Chapter Two. Chapter Four summarizes the results of our analysis.

CHAPTER TWO

An Illustrative Model

Historically, NASA and DoD have maintained and improved their large, national-class aeronautics ground-test capabilities to support their aeronautics research, development, testing, and evaluation and continuing program sustainment. These test capabilities were freely available to internal programs, which generally had only to schedule their facility time and prepare their models. After the Cold War, however, demand for aeronautics testing declined. At the same time, the cost of maintaining aging facilities built in the early years of the Cold War increased.

Calls in the late 1990s for full cost recovery for NASA ground-test facilities led to budgetary crises. Three factors combined to contribute to declining demand for testing and pushed many facilities toward obsolescence: sudden price shock (the result of adjusting prices to recover a greater share of costs); reduced defense spending in the 1990s, which led to fewer aeronautics program starts; and the aging of the wind-tunnel infrastructure, which was built primarily in the 1950s and 1960s (Ohlandt et al., 2011).

In 2006, NASA established the Aeronautics Test Program (ATP) to support major ground-test facilities across the NASA organization. Currently, NASA research centers (i.e., Ames Research Center, Glenn Research Center, Langley Research Center, and Dryden Flight Research Center) have operational responsibility for the facilities, and ATP provides operational subsidies for strategic capabilities and makes maintenance and improvement investments that support the whole NASA enterprise and U.S. aeronautics leadership. Since the establishment of ATP, NASA facilities have continued to experience a decline in use. Between 2006 and 2011, wind-tunnel testing at NASA facilities decreased by half, falling from more than 20,000 user occupancy hours in 2006 to just slightly more than 10,000 user occupancy hours forecast for 2011. During the same period, a loss of approximately $34 million in annual revenues generated from fees charged to wind-tunnel test facility users occurred (George, 2010).

To shed light on how an alternative pricing policy might affect NASA test facilities, RAND developed a simple economic model of the costs and benefits that accrue from operating a hypothetical wind-tunnel test facility. In fact, NASA operates a diverse set of test facilities (see Antón et al., 2004). As of June 2007, NASA actively operated ten subsonic, six transonic, six supersonic, and ten hypersonic wind tunnels at six different locations. The model presented here is general in that it specifies a framework for conceptualizing benefits and costs associated with test activities without having to parameterize assumptions to any particular facility. Table 2.1 summarizes the modeling notation used through this report.

Table 2.1
Summary of Notation

Notation	Definition
t	Annual user occupancy hours
$U(t)$	Annual utility derived by wind-tunnel users at t hours of use
V	National security benefit associated with keeping the facility operational
$B(t)$	Total annual benefits of the wind tunnel, equal to $U(t) + V$
F	Annual fixed cost of wind-tunnel operations
M	Marginal cost associated with one hour of use
$C(t)$	Total annual cost of operating the wind tunnel, equal to $F + Mt$
P	Price per hour of use paid by user
A	Annual fixed fee before it is divided among users
S	Annual partial subsidization of fixed costs offered by NASA
$CS(t)$	Annual consumer surplus, equal to $U(t) – Pt – A$
$BS(t)$	Annual operator budget shortfall, equal to $Pt + A – F – Mt$; see table note
$NB(t)$	Annual net benefit, equal to $B(t) – C(t) = CS(t) + V + BS(t)$

NOTE: According to government accounting rules, government wind-tunnel operators should require that $S = BS(t)$ at the end of the fiscal year. A continuing challenge is that $BS(t)$ is a function of t but that S is not. Although government operators cannot borrow from credit markets to compensate for this, they can borrow against maintenance. By pushing maintenance requirements into future years, operators can create scenarios where $BS(t) > S$ until the capability fails.

Benefits

This analysis considers two types of benefits derived from NASA wind tunnels. First, there are benefits that accrue directly to projects that use test facilities. We denote these benefits by the notation $U(t)$ and assume that they vary with annual user occupancy hours, t.[1] Second, there are national security benefits associated with having the strategic capability to conduct critical test activities as necessary. We denote the strategic value of keeping test capabilities available by V.

The total benefits of a wind tunnel facility, $B(t) = U(t) + V$, vary with the user benefits and national security benefits. We discuss each type of benefit in the subsections that follow.

User Benefits

NASA wind-tunnel facilities accommodate testing carried out by a variety of groups, including NASA researchers, DoD projects, and the U.S. aeronautics industry. In 2011, users affiliated with NASA are expected to account for slightly less than 50 percent of wind-tunnel test hours

[1] As is standard in economic models, we assume that test hours are incrementally allocated to the users with the highest marginal utility. This will occur whenever a pricing mechanism is in place since only users who receive marginal utility greater than the price will voluntarily opt to use a test facility.

at NASA facilities. Commercial and DoD users are expected to account for approximately 35 percent and 15 percent, respectively (George, 2010).

Users of NASA's wind-tunnel facilities benefit from the aerodynamic data they acquire through testing. Considerable variation exists across projects in terms of the value of test activities. Broadly speaking, wind-tunnel testing benefits can be categorized into three groups:

1. those associated with validating and verifying computational fluid dynamic (CFD) models[2]
2. those associated with the ability to characterize flight regimes that are difficult to model (e.g., turbulent flows, shock locations, poorly understood hypersonic regimes)
3. those associated with the ability to produce aerodynamics performance data with greater accuracy or more speed than computational models permit (although testing typically results in higher costs).

The marginal utility of testing may also vary with user requirements. For example, testing and evaluation (T&E) activities may be more urgent than test campaigns conducted for basic research and development (R&D) due to schedule requirements and the potential greater value of T&E projects. This difference should be reflected in estimates of different users' willingness to pay for test services. A little bit of testing to validate computational tools and methods, and in the case of unknown behavior, is of great value, but, in general, each additional test provides fewer benefits. The continuing development of CFD has greatly amplified this outcome. However, at some point in every project, the time and monetary costs associated with designing, developing, and analyzing additional tests make testing no longer cost-effective, even when facility usage fees are set at zero.

We let $U(t)$ represent the utility gained by users from t hours of test service; this utility value takes into account any test costs that the project incurs that are not associated with NASA's test facility pricing, including costs associated with consumables (e.g., electricity, fuel, cryogenics), user labor, test models, results analysis, and project schedule delays.[3] To allow comparison with costs, we assume that $U(t)$ is expressed in dollars. The derivative of $U(t)$, $U'(t)$, effectively represents what economists call an *inverse demand curve* (Varian, 1992). In this case, the inverse demand curve describes the price per hour of test time that can be charged to achieve a certain number of annual user occupancy hours, t.[4] To increase utilization, a lower price per hour of utilization must be charged. This implies that the second derivative of total utility is negative—i.e., $U''(t) < 0$ for all t—which is indicative of the fact that the marginal utility of testing declines as users engage in more testing. Our definition of $U(t)$ also

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[2] This suggests that wind-tunnel testing complements CFD. But, as discussed elsewhere in this report, CFD also serves as a substitute for wind-tunnel testing. Conventional wisdom is that the substitution effect has played a greater role, contributing to the general decline in wind-tunnel test activity over the past decade.

[3] The analysis performed here assumes that those who engage in testing are the final consumers of the information generated. In practice, however, users from industry may compete with each other in downstream markets. As a result, test facility pricing could affect competition or industry structure in markets that benefit from wind-tunnel test activities. To keep the analysis focused and manageable, we do not explore this. Furthermore, because the costs associated with wind-tunnel testing are generally a small fraction of overall product costs for items that rely on wind-tunnel testing, we do not anticipate that changes in test facility pricing will have a noticeable effect on downstream competition.

[4] If users are charged a price P per hour of use and an estimate of $U'(t)$ is available, the total hours of use can be determined by finding the point at which $U'(t) = P$.

allows for a marginal utility, $U'(t)$, that can become negative if additional testing is producing little or no benefit but costs associated with consumables and user labor remain.

Strategic National Security Benefits

Due to the national security aspects of aeronautics testing, the federal government has historically funded and operated national-class wind-tunnel test capabilities. Industrial espionage concerns and national security issues make the sustained availability of domestic facilities a national priority. We denote the strategic national security benefits by V and assume that it remains constant. In economic terms, V should be thought of as an *external benefit* of maintaining test facilities. It is an external benefit in the sense that it, like national defense, accrues broadly to citizens of the United States and is not directly internalized by any specific users.[5] Although the size of V is very difficult to estimate, it has been used to justify providing large subsidies to test facilities in order to maintain capabilities. For the purpose of comparing V with costs, V reflects the value of maintaining capabilities over some period (in our case, a year).

Costs

National-class wind tunnels are extremely expensive to build and operate.[6] Capital costs to construct a new test facility can be in the hundreds of millions of dollars. Millions of dollars in fixed annual operating costs are needed to maintain both the large infrastructure and its highly specialized staff. We denote the annual fixed costs of a test facility by F, which includes any financing charges associated with the facility's capital costs. There are also costs that vary directly with usage. We denote the cost per hour of use by M. Therefore, total cost, $C(t)$, is equal to $F + Mt$.

Our analysis involves several simplifying assumptions that we wish to note here. First, marginal cost may in fact be nonconstant. For example, when usage exceeds a certain point, the facility may need to add staff, which could cause the marginal cost to increase (before it eventually decreases again). Assuming a nonconstant marginal cost would complicate the analysis but would not change our key findings, so, to keep the analysis as simple as possible, we assume a constant marginal cost.

Second, a facility may at some point become physically incapable of accommodating additional use. Our analysis does not consider capacity limitations that might make a particular facility unable to accommodate additional demands for testing beyond a certain level. Although this could, in theory, become an issue, it seems more likely that, given the dramatic decline in wind-tunnel testing that has occurred over the past decade, physical capacity constraints are not likely to affect the vast majority of NASA's facilities.

[5] Furthermore, because it is associated with the *availability* of test capacities, one might think of V as the option value associated with being able to access test capabilities if they are needed to support programs or products developed in the national interest (e.g., in the case of new military equipment developed to address a new national security threat).

[6] The Aeronautics and Space Engineering Board, National Research Council (1994) estimates the following amortized annual capital costs associated with constructing a new wind tunnel: low speed, \$32 million; transonic, \$85 million. It estimates operating costs for each type at \$5,000 and \$16,000 per user occupancy hour, respectively. These estimates are over 15 years old, and costs today are likely considerably higher; however, estimating related cost factors was outside the scope of the research documented in this report.

Third, we do not attempt to evaluate how pricing structures allocate over time the recuperation of sunk costs or the cost of building new facilities. We also do not attempt to evaluate how pricing affects higher-level operational issues, such as cost control and innovation.

Comparing Costs and Benefits at Different Levels of Use

Figure 2.1 illustrates how benefits and costs might vary with usage. In this example, the wind tunnel produces positive net benefits—expressed as $NB(t) = B(t) - C(t)$—when test activities fall in the range of $\underline{t}$ to $\bar{t}$. If, for whatever reason, test activity falls outside this range, economic reasoning suggests that users and taxpayers are worse off overall by allowing the facility to operate and that the facility should be shut down or have its usage capped. As we discuss in the next chapter, how test services are priced can affect the level of usage and, therefore, whether a facility is operating within this range. It should also be noted that the larger the value of V, the wider the tolerable range of usage. Throughout the remainder of the report, we assume that the facility being modeled is generating enough benefits to justify its costs and that, therefore, it should remain open.

From an economic perspective, the facility depicted in Figure 2.1 is most efficiently utilized at t^*. It is at this point that net benefits—expressed as $NB(t) = B(t) - C(t)$, which represents the difference between benefits and costs—are maximized. As Figure 2.2 illustrates, at t^*, marginal benefits, $B'(t^*) = U'(t^*)$, exactly equal marginal costs, $C'(t^*) = M$. This efficiency requirement becomes obvious once one looks at the first-order condition to the optimization problem of maximizing net benefits; i.e., $NB'(t^*) = B'(t^*) - C'(t^*) = U'(t^*) - M = 0$.

Notice that t^* does not depend on V. That is, as V increases or decreases, the optimal usage level does not change. This is useful to note, since V cannot be estimated easily, might be the subject of substantial disagreement, and might change over time.

Figure 2.1
Notional Example of the Benefits and Costs of Wind-Tunnel Use

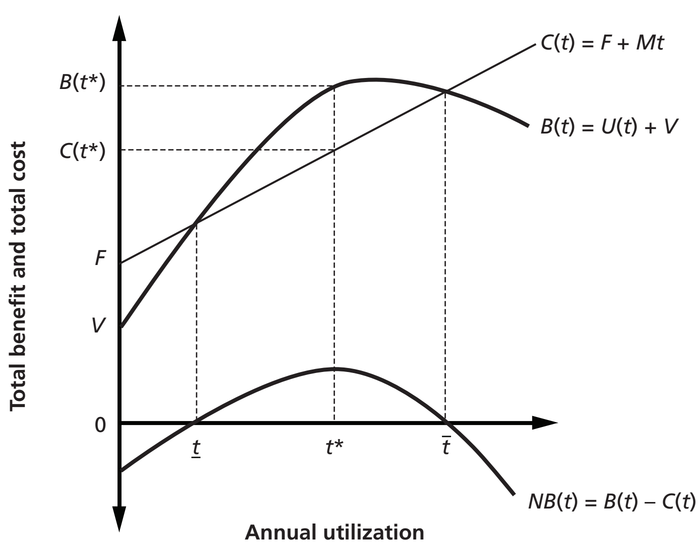

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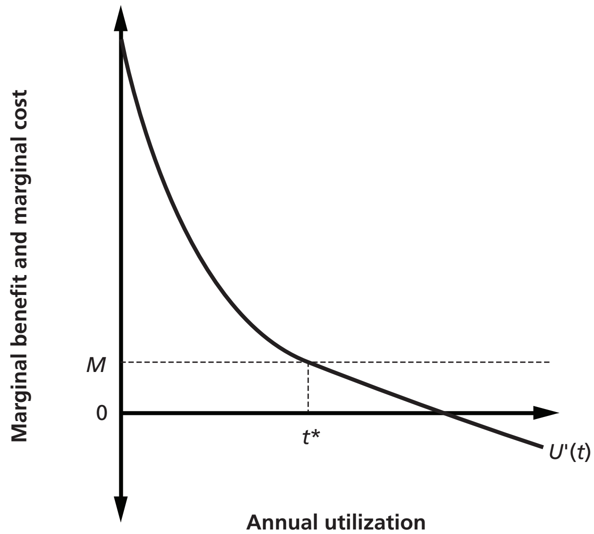
Figure 2.2
Notional Example of the Marginal Benefits and Marginal Costs of Wind-Tunnel Use



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CHAPTER THREE

Comparing Alternative Methods for Pricing Wind Tunnels

Since ATP's founding in 2006, fee-revenue levels for its facilities have been in decline, and government funding for operations has not increased significantly. Thus, the total funds currently available are insufficient to both operate NASA's existing wind tunnels and invest in new test capabilities. This makes determining appropriate pricing schemes very important.

In this chapter, we analyze six different pricing approaches for test facilities:[1]

- **Marginal cost pricing (MC).** Each user is charged an hourly fee equal to the test facility's marginal operating cost.
- **Two-part pricing with full cost recovery (TPP).** Each user is charged both a fixed fee and a variable fee. The fixed fee (i.e., an annual subscription fee or test setup fee) is set to approximately balance the facility's annual budget; the variable fee equals the facility's marginal operating cost. (One could think of this approach as MC with a subscription fee.)
- **Two-part pricing with partial subsidization (TPPS).** As in TPP, each user is charged both a fixed fee and a variable fee. However, the fixed fee is set to recover only some of the facility's annual budget; NASA is expected to subsidize the rest.
- **Average cost pricing (AC).** Each user is charged a variable rate, determined annually, that is set to approximately recover all of the facility's costs.
- **Average cost pricing with partial subsidization (ACS).** As in AC, each user is charged a variable rate. However, the revenues collected cover marginal operating costs and a portion—but not all—of the facility's annual budget; NASA is expected to subsidize the rest.
- **No charge for use (NC).** Each user is granted access to the facility at no cost beyond the direct pass-through consumable costs, such as for electricity.

These six pricing strategies are summarized in Table 3.1. In the table, P denotes the price per hour of use, and A denotes the amount of revenue generated through a fixed fee under each pricing strategy. We let S denote the size of the partial subsidy provided under TPPS and ACS. We assume that $0 < S < F$, which implies that the partial subsidy covers some but not all of the

[1] The six pricing approaches described here represent commonly analyzed forms of pricing from the economics literature that we deemed most applicable to NASA test facilities. Others could have been included. For example, economists also generally assess the option of pricing facilities to maximize profits. Because NASA wind tunnels are a government service, we did not think it was appropriate to pursue this particular pricing approach. Another approach, employed if facilities are used so heavily that queues begin to form, is to use pricing to better manage wait times. Finally, various forms of auctions (e.g., discriminatory, uniform price, Vickery) can be used to sell test time at particular facilities, but we do not consider this option. For more information, see Tirole, 1988.

Table 3.1
Summary of Approaches to Pricing Test Facilities

Pricing Approach	Price per Hour (P)	Fixed Fee Divided Among Users (A)
Marginal cost pricing	M	0
Two-part pricing with full cost recovery	M	F
Two-part pricing with partial subsidization	M	$F - S$
Average cost pricing	$M + \frac{F}{t}$	0
Average cost pricing with partial subsidization	$M + \frac{F - S}{t}$	0
No charge for use	0	0

fixed costs. We wish to note that this analysis assumes that government and nongovernment users are charged identically, although this is not truly the case. (In practice, NASA charges nongovernment users an additional overhead cost. To keep the analysis simple, we do not incorporate this fact into the simple model described in this report.) We also wish to note that, because of legal hurdles and other issues, NASA is unlikely to ever pursue a no-charge pricing scheme with external customers. However, the pros and cons of no-charge pricing remain applicable to other government departments and even to other NASA directorates that might be users of NASA wind tunnels but do not have budgetary responsibility for them.

Notice that the information required to implement these pricing policies includes both (1) the cost structure of the test facility and (2) how demand for testing can change with the price structure (so that utilization can be predicted). The pricing approaches that seek to recover some or all of the fixed costs also require that NASA estimate the size of its fixed costs and determine usage levels. Given that projected and actual demand will naturally differ to some degree,[2] test revenues could be higher than expected in some years and lower than expected in others.

When firms compete to provide goods and services, market forces tend to drive prices toward marginal costs (Varian, 1992). However, in industries with large fixed costs, this can lead to significant losses, making a competitive environment unsustainable. In such instances, the government may step in as a provider, as it has in the case of aeronautics test capabilities.[3]

The two-part pricing schemes described in this report are similar to marginal cost pricing in that users continue to pay a price per hour of use equal to marginal costs. However, they also introduce a fixed fee that users would have to pay annually to access NASA facilities (Hendriks and Myles, 2006). For both forms of two-part pricing, the fixed fee can be spread across users in a variety of ways. For example, it could be paid annually by the parent organization (e.g., the

2 In addition to the obvious uncertainties involved in predicting future use of a facility, NASA's internal policies on cost reimbursement and facility subsidies can also introduce estimation biases if facility operators try to "game the system."

3 In these instances, a single firm might take control of the industry and operate as a "natural monopoly" (Varian, 1992). The government is likely either to regulate the price the monopolist can charge or to enter the market as a provider. Retail electricity markets are an example of the former case: Investor-owned utilities effectively have a monopoly on the provision of power in areas they service, and the rates they can charge are heavily regulated. Transit services are an example of the latter case: They are often provided by government agencies and are heavily subsidized.

Air Force, a company) through a subscription fee. Alternatively, the facility could charge each user a fixed fee for the planning, preparation, and installation associated with the test's equipment and models, regardless of the total test time. Such a fee could not, however, depend on how much time the project spends at the facility, since this would mimic an hourly fee.

Average cost pricing is an easy-to-implement alternative to two-part pricing, and it can result in financially self-sustaining facilities. It has been used, for example, as a basis for setting regulated retail rates for electricity in the United States. A no-charge system, on the other hand, makes test facilities completely reliant on NASA for funding.

To determine usage levels under different pricing schemes, we apply basic economic principles that suggest that users will opt to use test services up to the point at which the marginal benefits they enjoy, $U'(t)$, equal the marginal cost, P (Varian, 1992). So, total usage of a facility can be determined by the t that causes $U'(t) = P$. When the price increases, utilization falls. Similarly, when price decreases, utilization rises.

The Goals of Pricing

We evaluated the six pricing approaches against three goals that the government and NASA are likely to value. The goals we considered are summarized in Table 3.2.

Economists have long advocated for setting user charges for government services at a price that is equal to marginal cost because doing so is efficient. This pricing strategy gives users an incentive to consume services up to the point at which the marginal benefits they enjoy equal the marginal provision cost. From an economic-efficiency perspective, pricing above marginal cost leads to underutilization, and pricing below marginal cost leads to overutilization. In our analysis, marginal cost pricing achieves an efficient level of usage because $P = M$.[4] Both of the two-part pricing schemes have the potential to result in an efficient level of utilization

Table 3.2
Goals Considered in the Analysis

Goal	Description
Promote efficient use of test facilities (i.e., efficiency)	Efficiency is measured in terms of the net benefits generated by the facility under the pricing scheme. Net benefits are maximized when users opt to use the test facility up to the point at which the marginal benefits they enjoy equal the marginal cost. In Figures 2.1 and 2.2, this point is denoted by t^*.
Generate revenue to offset costs (i.e., fiscal impact)	NASA has limited financial resources. All else being equal, pricing approaches that are able to offset costs to a greater degree are more attractive than those that do not, since they reduce budget shortfalls. Revenue generation is measured in terms of the difference between revenues and costs.
Produce a fair allocation of costs across beneficiaries (i.e., fairness)	We evaluate fairness in terms of the allocation of costs between users and NASA (which effectively represents taxpayers). A fair allocation is one that results in users paying for the marginal costs they generate while leaving fixed costs to be split between the users and NASA. This is deemed fair because of the national security benefits that taxpayers receive from these facilities.

[4] Note that economic efficiency is concerned only with whether total benefits minus total costs are maximized; it is not concerned with how those benefits and costs are distributed between users and NASA. Economic efficiency as a metric is therefore subject to criticism. We address this shortcoming by including a measure of "fairness" in our analysis.

because they also set P to equal M. However, if some users are unwilling to pay fixed fees and are therefore ineligible to use NASA's wind tunnels, there will be some efficiency loss relative to marginal cost pricing (see Tirole, 1988; Hendriks and Myles, 2006).[5]

Given the fiscal constraints that many government agencies face, levels of user charges are more likely to be motivated by budgetary pressures than by efficiency concerns (Borge, 2000). In such environments, pricing approaches that lead a facility to become financially self-sufficient are likely to be attractive. Our second criterion, fiscal impact, assesses how each pricing approach affects NASA's budget.

Government agencies are not concerned with efficiency and fiscal impact alone; the "fairness" of the pricing policies they adopt is also scrutinized. Fairness can be defined and measured in a variety of ways (Ecola and Light, 2009). What one person views as fair may be judged unfair by another. In NASA's case, the *benefit principle* and *cost principle* from the public finance literature (Mankiw, 2008; Musgrave and Musgrave, 1989) are appropriate notions of fairness that can be applied differentially to fixed and variable costs. In this report, our definition of *fairness* is based on the benefit and cost principles, but we recognize that other notions of fairness may be applicable.

The benefit principle suggests that those who benefit from a service should provide financial support for that service. The cost principle suggests that those who generate costs should pay those costs. As postulated here, NASA wind tunnels provide two types of benefits: direct benefits to projects that use the test facilities and national security benefits that accrue broadly to U.S. citizens. This suggests that both the projects that use facilities and NASA itself (acting in the interest of taxpayers) should bear some of the fixed costs associated with maintaining wind-tunnel capabilities. In fact, ATP's 2009 strategic plan states that "NASA has a role in providing test capabilities that are not economically viable as independent business and thus not available elsewhere" (Aeronautics Research Mission Directorate, National Aeronautics and Space Administration, 2009), which suggests the national importance of NASA's test facilities. However, if one applies the benefit and cost principles to the marginal costs incurred at test facilities and also recognizes that the users both impose that cost and reap the benefits, one must conclude that projects should pay for all of the direct (marginal) costs they generate.

In terms of fairness, two-part pricing with subsidization and average cost pricing with subsidization spread the fixed costs between NASA and users while forcing users to pay for all of the direct costs they generate. Note, however, that the differentiation requiring costs borne by users and costs borne by taxpayers is inevitably complicated when one realizes that many of the projects that use wind-tunnel test facilities are in fact funded through federal programs supported by general tax revenues. Nevertheless, we believe that the distinction is a useful one, since a portion of NASA test facility users are private companies that, to some extent, enjoy greater profits when they pursue value-added test activities.

[5] At this stage, we do not have a good sense of how sensitive users are to fixed and variable fees. We have also not investigated in any detail the trade-offs associated with alternative ways of setting the fixed fee. Additional research along these lines is necessary if NASA deems a two-part pricing strategy worthy of consideration.

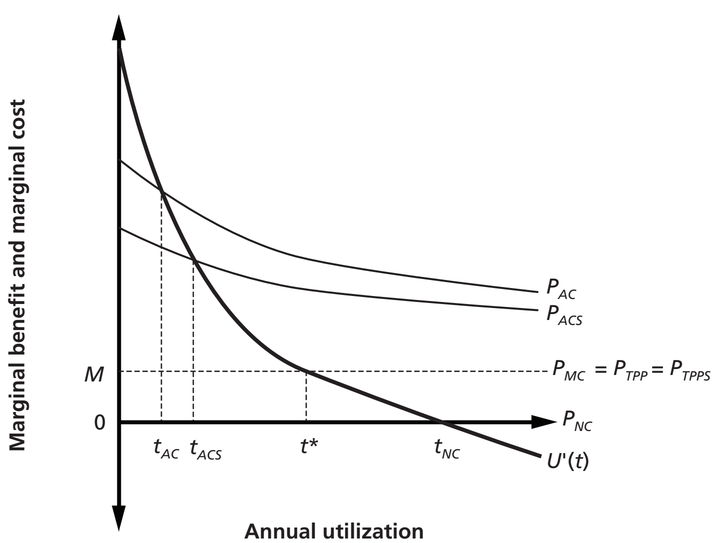
Outcomes Under Alternative Pricing Approaches

The amount of testing that occurs depends to some extent on how the price per hour of testing is determined. The fixed-fee level does not affect usage in this simple example. As indicated earlier, this assumption may be questionable, since having to pay a "subscription" fee may cause some potential users to altogether forgo testing at NASA facilities. This is not formally considered in our simple example, but it is a very real possibility. In such a case, NASA might choose to set a fixed fee that minimizes the number of organizations that decide not to use its test facilities. We did not investigate the specific terms of the fixed-fee arrangement, but, if a two-part pricing approach is adopted, the issue merits additional research.

Figure 3.1 illustrates each of the hourly pricing approaches and the resulting level of total usage. Usage is lowest under average cost pricing (represented by P_{AC}) because this approach results in the highest overall price per hour of use. Average cost pricing with partial subsidization (represented by P_{ACS}) produces greater demand, but utilization is still below the optimal level, t^*. Marginal cost pricing (represented by P_{MC}) and both forms of two-part pricing—two-part pricing with full cost recovery and two-part pricing with partial subsidization (represented, respectively, by P_{TPP} and P_{TPPS})—achieve the optimal level of utilization. A no-charge approach (represented by P_{NC}) leads to overutilization. To summarize, $t_{AC} < t_{ACS} < t^* = t_{MC} = t_{TPP} = t_{TPPS} < t_{NC}$, where the subscript represents the type of pricing pursued.

For each of the six pricing approaches, Table 3.3 summarizes overall net benefits, as well as the net benefits that accrue to users and to NASA's budget. In economics, the consumer net benefits are commonly referred to as *consumer surplus* (CS). One can rank the CS levels obtained under each pricing policy by analyzing the formulas shown in Table 3.3. It is clear that users fare worst under average cost pricing and best under no-charge pricing. Furthermore, $CS_{AC} < CS_{TPP} < CS_{TPPS} < CS_{MC} < CS_{NC}$. How to rank CS_{ACS} depends on the utility

Figure 3.1
Utilization Rates Under Alternative Pricing Approaches



RAND *TR999-3.1*

function and the level of subsidy, S. It is greater than CS_{AC} and lower than CS_{TPPS}, but it may be greater than or less than CS_{TPP}.[6]

In terms of budget shortfall (BS), average cost pricing and two-part pricing with full cost recovery produce, by design, no budget shortfall. On the other hand, no-charge pricing produces the largest budget shortfall. We can rank each strategy in terms of its budget shortfall as follows: $0 = BS_{AC} = BS_{TPP} < S = BS_{ACS} = BS_{TPPS} < F = BS_{MC} < BS_{NC}$.

Table 3.3 further summarizes the results by reporting the overall net benefits produced by wind-tunnel operations.[7] This analysis allows us to rank most of the pricing strategies. In particular, we see that net benefits are equal and maximized under marginal cost pricing and both forms of two-part pricing (two-part pricing with full cost recovery and two-part pricing with partial subsidization). No-charge pricing and both forms of average cost pricing perform worse relative to the other set of approaches. We can see that that average cost pricing with partial subsidization performs better than average cost pricing without partial subsidization, but, without making additional assumptions, it is not possible to determine how a no-charge policy ranks relative to the two forms of average cost pricing. In summary, one can show that $NB_{AC} < NB_{ACS} < NB_{MC} = NB_{TPP} = NB_{TPPS}$ and that $NB_{NC} < NB_{MC} = NB_{TPP} = NB_{TPPS}$, but NB_{NC} may be greater than or less than NB_{AC} and NB_{ACS}.[8]

Table 3.3
Outcomes Under Alternative Pricing Approaches

Pricing Approach	Consumer Surplus *a*	Budget Shortfall *b*	Net Benefits *c = a – b + V*
Marginal cost pricing	$U(t^*) - Mt^*$	F	$U(t^*) - Mt^* - F + V$
Two-part pricing with full cost recovery	$U(t^*) - Mt^* - F$	0	$U(t^*) - Mt^* - F + V$
Two-part pricing with partial subsidization	$U(t^*) - Mt^* - (F - S)$	S	$U(t^*) - Mt^* - F + V$
Average cost pricing	$U(t_{AC}) - Mt_{AC} - F$	0	$U(t_{AC}) - Mt_{AC} - F + V$
Average cost pricing with partial subsidization	$U(t_{ACS}) - Mt_{ACS} - (F - S)$	S	$U(t_{ACS}) - Mt_{ACS} - F + V$
No charge	$U(t_{NC})$	$F + Mt_{NC}$	$U(t_{NC}) - Mt_{NC} - F + V$

[6] Note that the subsidy's actual cost to the taxpayer will exceed S, due to the economic cost of raising taxes.

[7] If the facility is not used at all, the net benefits would equal $V - F$. Facility use would cause the net benefits generated by the facility to grow, as long as t is less than or equal to t^*. Additional utilization beyond t^* would cause net benefits to decline, since marginal cost would exceed the marginal benefits that accrue to users.

[8] NB_{AC} and NB_{ACS} will tend to be greater than NB_{NC} when marginal cost, M, is larger and when fixed cost per user occupancy hour (F/t) are smaller.

CHAPTER FOUR

Discussion

The model presented in the previous chapters shows the trade-offs involved in the six alternative approaches to pricing NASA wind-tunnel use. Table 4.1 summarizes our findings (in nontechnical terms) with regard to the three criteria we considered. Our ranking system—consisting of *good*, *moderate*, *poor*, and *very poor*—is intended to reflect each pricing strategy's relative performance. For example, if a pricing strategy's fiscal impact is rated "good," its revenues cover all of NASA's costs; if it is "moderate," some of the facility's fixed costs and all of its variable costs are covered; if it is "poor," the pricing strategy covers only variables costs; if it is "very poor," none of the facility's costs are covered.

Table 4.1
The Performance of Alternative Pricing Approaches Against the Three Criteria

Pricing Approach	Efficiency	Fiscal Impact	Fairness
Marginal cost pricing	Good	Poor	Moderate (NASA pays for all fixed costs)
Two-part pricing with full cost recovery	Good[a]	Good	Poor (Users pay for everything)
Two-part pricing with partial subsidization	Good[a]	Moderate	Good (Users and NASA split fixed costs)
Average cost pricing	Moderate to poor[b]	Good	Poor (Users pay for everything)
Average cost pricing with partial subsidization	Moderate	Moderate	Good (Users and NASA split fixed costs)
No charge	Moderate to poor[b]	Very poor	Poor (NASA pays for everything)

[a] The model outlined here assumes that the fixed fees imposed under a two-part pricing scheme will not discourage any potential users from participating in NASA's test facility user base. This means that both two-part pricing schemes—TPP and TPPS—perform well in terms of efficiency. This assumption may be questionable, however, and, if a two-part pricing system is pursued, it merits additional research.

[b] AC and NC policies can be less efficient than ACS because they can result in a price that is further from the marginal cost when both fixed and marginal costs are substantial. However, facilities with marginal costs approaching zero would find NC to be more efficient than ACS unless the subsidy approaches 100 percent of fixed costs. Similarly, facilities with fixed costs approaching zero would find AC to be more efficient than ACS unless the subsidy approaches zero.

Marginal cost pricing and two-part pricing, both with and without subsidization, perform well in terms of efficiency. As discussed earlier, the larger the fixed fee associated with two-part pricing, the more likely potential users are to opt out of paying the fee, thereby making them ineligible to use NASA test facilities. Although the simple model presented here does not account for this possibility, it is noted in Table 4.1.[1] The no-charge policy and both forms of average cost pricing perform moderately or poorly, but for different reasons: Both forms of average cost pricing would lead to underutilization of test facilities, and a no-charge approach would lead to overuse. The extent to which average cost pricing and a no-charge approach are less efficient depends on the price elasticity of demand. That is, the more price-elastic users are, the greater the efficiency loss experienced under average cost pricing and a no-charge system will be, relative to marginal cost pricing.

A no-charge approach performs very poorly in terms of fiscal impact on NASA. This is because, under this option, NASA pays for both fixed and variable costs. On the other hand, two-part pricing with full cost recovery and average cost pricing produce revenues that equal costs.

In terms of fairness, two-part pricing with subsidization and average cost pricing with subsidization are likely to be viewed as attractive pricing options, since users pay for the marginal costs they generate and the fixed costs are covered by both users and NASA (representing taxpayers). Both two-part pricing with full cost recovery and average cost pricing perform poorly in terms of fairness because users must pay for all a facility's fixed costs, even though a facility's availability is dictated by strategic national security considerations that are not tied to any particular user. A no-charge system performs poorly in terms of fairness because it forces NASA to pay all costs (both fixed and marginal).

As this analysis suggests, no pricing strategy performs well in terms of three criteria. In selecting among pricing alternatives, NASA will be forced to accept better performance against one criterion but poorer performance against another. It should be noted, however, that the no-charge policy performs poorly across all three criteria. Specifically, a no-charge policy would lead to overutilization of facilities from an efficiency perspective, would result in the largest budget shortfall of any of the pricing strategies we reviewed, and would perform poorly in terms of fairness because NASA would be forced to pay all costs even though users outside the agency would benefit from using NASA's test facilities. The efficiency shortcoming of a no-charge system could potentially be reduced if mechanisms were put in place to restrict overuse (e.g., prioritization mechanisms, restrictions on test hours). However, under the no-charge pricing scheme, nothing can be done to change the fact that NASA must entirely fund the test facility. As mentioned earlier, legal hurdles make it extremely unlikely that NASA will provide no-charge test services to external customers. However, this analysis is equally applicable to other federal departments and even to NASA directorates that are wind-tunnel customers but have no direct budgetary responsibility for the wind tunnels.

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1 Two-part pricing of the type assumed here can also be less efficient than marginal cost pricing if the former affects entry costs in downstream markets. This can result in too few firms with too much output per firm in the downstream market (Ordover and Panzar, 1982).

Other Issues

There are multiple complicating factors, and there are more-complex forms of pricing that the simple model described in this report cannot accommodate. These factors are discussed in the subsections that follow.

User Sensitivity to Pricing and Potential Competition

We have conducted no formal analysis of the sensitivity of users to alternative pricing schemes. This is due in part to the fact that we do not have the data or surveys that would support such an analysis and in part to the time and resource limitations associated with this project. As noted earlier, some of the findings related to efficiency depend on how users respond to pricing.

If users do not change their testing behavior in response to pricing (i.e., if users are price inelastic), the form of pricing that is selected becomes less important from an efficiency perspective. But the declining use of NASA test facilities—coupled with the growing capability of CFD—suggests that users are indeed likely to be sensitive to charges. In our analysis, this is implicitly represented in the shape of the marginal benefit curve depicted in Figures 2.1 and 2.2.

To more fully understand users' sensitivity to price, analysts could examine past data on test facility usage and prices. This work could be supplemented with a survey of users that is designed to obtain a better understanding of their test options and their responses to changes in the price and availability of test options provided by NASA. In some cases, it may be possible for users to choose from among multiple wind-tunnel test facilities; in this case, an increase in the price of using one facility might cause users to move their business to other facilities. Surveys and past data could potentially be used to better understand user options and preferences at different price points.

Our analysis also does not take into account potential competition from commercially owned and operated test facilities. Our focus was on generic pricing models for unique, national-class ground-test capabilities; alternatives for these capabilities are not readily available, and, in general, industry cannot afford to duplicate them. However, the effects of competition must be taken into account when deciding how to price use of a specific facility.

Fluctuating Demand

Demand for wind-tunnel test capabilities is primarily driven by major aircraft and spacecraft programs, whose developmental cycles are on a decadal scale. Within any single program, testing also occurs in waves related to phases, such as concept development, full-scale development, and production validation (American Institute of Aeronautics and Astronautics, 2003). Demand for national-class wind-tunnel facilities has become highly cyclic since the nation has moved toward developing just one new major fighter aircraft design and just one large commercial airplane per decade (Antón et al., 2004, p. 10). Moreover, changes in government annual appropriations, program planning changes, unanticipated program problems or delays, and unanticipated developmental or sustainment problems can rapidly alter test requirements. For wind-tunnel operators, this situation results in a highly variable and unpredictable usage pattern and an inability to reliably forecast usage beyond 6–12 months in the future. Given large-capacity requirements to meet tight program schedules, this situation all but guarantees significant periods of little to no utilization of most types of wind-tunnel test capabilities, punctuated with important but intermittent needs.

To a large extent, pricing cannot address these fluctuations, since they stem from more-fundamental issues that drive annual fluctuations in test demand. However, in attempting to recover a portion of fixed costs, an agency can modify pricing to help smooth the budgetary effects of these fluctuations. Specifically, in years of low demand, fees can be increased to recoup more fixed costs. An obvious downside of this strategy is that, in years of low test activity, the higher price may further discourage testing. Consequently, if money raised through pricing can be carried forward to offset future loses, one might consider raising fees in years of high demand and lowering them in years of low demand. This strategy would smooth demand but create greater year-to-year variability in budget performance.

Capacity Issues

If facilities are consistently experiencing demand in excess of capacity, queues for use will form. When this occurs, NASA can take one of two steps. First, it could create additional testing shifts to effectively increase capacity. This would require reallocating staff and other resources to facilitate the additional hours of operation, which may be difficult to implement. At some point, a facility will be operating at true physical capacity, and no steps short of building a duplicate facility could allow it to accommodate additional demand. Second, NASA could raise usage fees to ration the available capacity and eliminate queues. The additional revenue raised by this step could then be invested in building new test facilities to accommodate the increased demand.

Priority Pricing

If more users wish to utilize NASA test facilities than can effectively be accommodated during certain periods, NASA could institute the use of priority pricing (Marchand, 1974; Wilson, 1989; Rao and Petersen, 1998). Priority pricing essentially gives preferential service to users that pay a premium price for use. For example, two rates might be charged for test services. Users paying the lower rate would be allowed to use test facilities as long as users paying the higher rate were not using the facility, but the former users would have to defer to the latter. In this situation, users with high-priority test needs could reduce their wait time by paying the higher rate. The methodology we employed in our research cannot analyze this scenario because it does not consider schedule delay. However, such a pricing scheme might be appropriate for meeting the needs of both the T&E and R&D communities.

Prioritizing Users via Committee

If priority pricing is not pursued but scheduling issues are common, prioritization via committee may be pursued. In this situation, the committee would consider the perceived merits of the different proposed test activities and allocate test time accordingly. This could result in outcomes that some users view as unfair or biased. Furthermore, the committee might not understand or be fully aware of the potential importance of certain test activities that some users may be pursuing. Nevertheless, such a mechanism is likely to be necessary when a single price is charged or especially if testing is made free to users.

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