Maintaining NASTRAN:

The Politics and Technics of Aerospace Computing

by

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(Abstract)

This thesis describes a process of how NASA maintained the NASTRAN (NASA Structural Analysis) computer program. Chapter one addresses my theoretical concern and suggests to learn from both critical theorists and social constructivists. Chapters Two and Three tell the story of NASA and NASTRAN, a computer program developed by NASA for solving problems of airframes and space structures. The story of NASA and NASTRAN demonstrates a structural imbalance between social groups of NASTRAN and results in the revision of NASTRAN in favor of aerospace users. Chapter Four recounts Feynman's concerns regarding the conflicts between managerial and engineering expertise. I discuss these issues in light of the story of NASA and NASTRAN.

Table of Contents:

Acknowledgment

First and foremost, I dedicate this work to my parents. Without them, I would not have had the chance and support to finish this work. My scholarly debt is to Gary L. Downey, my graduate advisor, who was extraordinarily generous with his time, and who never relaxed his standards. I have benefited so much from working with him. My committee members, Ellsworth R. Fuhrman, Steve W. Fuller and Paul E. Ceruzzi, stimulated my thought in each of their different ways and served as wonderful discussants. I deeply appreciate their help. Richard M. Burian and Anne McNabb offered their warmest support to me. My fellow graduate students, Adam H. Serchuk, David Murphree, Mary E. Cato and Michael Seltzer, have read through several of my drafts and helped me improve my awkward English. David Ferro, Douglas Taylor and Ahmed Bouzid have been my pleasant discussants on different aspects of this work.

For data collection, I obtained most of the primary sources from the National Air and Space Museum, NASA History Office and Langley Research Center. I would like to express my gratitude to archivists Lee Saegesser and Bill Skerrett of the NASA History Office. Barbara Newton from Record Management at Langley helped me gather correspondence between the NASTRAN office and industries. I appreciate Joseph Walz's generous help in providing a complete collection of NASTRAN Newsletters.

Chapter 1

Introduction and Literature Review

In 1966, the National Aeronautics and Space Administration (NASA) began a project aiming to "provide all NASA Centers, NASA contractors, universities, and industry with a comprehensive computer program that solves a wide range of problems encountered in the field of structural analysis."[1] The product of this project, roughly 1,000,000 machine language statements in tapes, was a computer program named NASTRAN (NASA Structural Analysis). The story of NASA and NASTRAN began with the Cold War and the Apollo program. Congress passed the National Aeronautics and Space Act of 1958 in early April. On October 1, 1958, it then disbanded the National Advisory Committee for Aeronautics (NACA) and formed the National Aeronautics and Space Administration (NASA). The intended mission for NASA was to compete with the Soviet space program throughout the 1960s. More specifically, NASA's mission was to put a few men on the moon and get them back safely. The project at the initial stage was set up as the "manned space program" to compete with the Soviet Union after the launching of Sputnik in 1957. As McDougall put it, this "technological temptation" for President Kennedy was the prestige of having Americans in space first.[2] A decade later, the successful Apollo 11 mission received attention in almost every corner of the world. For the entire 1960s,

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[1] *Final Report for NASTRAN Project*, prepared for Goddard Space Flight Center by Computer Sciences Corporation, contract no. NAS5-10049, March 2, 1970.

[2] For a detailed account, see Walter A. McDougall's "Chapter 7, The Birth of NASA" in *...the Heavens and the Earth: A Political History of the Space Age*, 1985, pp. 157-176.

the United States government invested tremendous amounts of resources and brainpower to prove its superiority over the Soviet Space Program.[3]

NASA played the leading role for this space endeavor. Nevertheless, after the Apollo 11 mission, NASA fell onto hard times. The moment of glory in celebrating "the giant leap for mankind" did not prevent a significant drop in NASA's budget. The U.S. space budget for NASA declined from 5.2 billion dollars in 1965 to 3.5 billion dollars in 1970.[4] By 1971, it had returned to its level in 1963, indicating that the heyday of space activities had finished. NASA's space program then needed to compete with other important political issues in Congress, such as health, energy and protection of environment. Furthermore, NASA not only had to compete with other important political issues, but also needed to prove itself as a major space agency. NASA had a crisis of legitimacy following Apollo. NASA sought new sources of legitimacy. Its strategy was to begin preparing a project that only NASA could do, which turned out to be the space shuttle project.

Compared to the political climate of the Apollo mission, NASA encountered a more difficult and hostile one this time. In the setting of the Cold War, the US space activities closely associated with DOD and its military purposes. The DOD sponsorship of basic research aroused opposition on university campus. The student protest movements of the late 1960s and early 1970s had military-sponsored research in the universities as its the main targets. After the student protest movements, the issue of scientific links to the military lay relatively dormant for most of the 1970s. At this political moment, NASA tended to emphasize its civilian spin-offs and increase its accountability in receiving support. In any case, the space issues in the post-Apollo years appeared much less important than in the Apollo years. In such a climate, NASA required, as a scientific journalist perceived it, a "deft and persistent salesmanship, a talent marked by careful acquiescence to political and economic realities and a willingness to bleed other programs,

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[3] Ibid.

[4] *Aeronautical and Space Report of the President*, transmitted to the Congress, January 1971, p. 114.

including the Apollo, to keep the Shuttle alive."[5] As NASA Administrator James C. Fletcher estimated, it would take six years (as a matter of fact, it took nine years) to "transform the shuttle from a drawing board dream to a flying reality."[6] From the Apollo mission to shuttle project, NASA's positions evolved from an aggressive and expansive space agency in the 1960s to a defensive and protective bureaucracy in the early 1970s. It was in this political context that the story of NASTRAN unfolded.

The unfolding of the story of NASTRAN could be chronicled in "the Apollo years" and "the post-Apollo years." I have outlined the contrast between the Apollo and post-Apollo years. Richard P. Feynman provides an interesting description of this contrast after his investigation of the Challenger Accident.[7] First of all, Feynman gives a picture of enthusiasm and anxiety during the Apollo years:

> When NASA was trying to go to the moon, there was a great deal of enthusiasm: it was a goal everyone was anxious to achieve. They didn't know if they could do it, but they were all working together.

Second, after the Apollo project, Feynman describes NASA as an over-swollen giant monster. The reproduction of the organization per se has become an urgent problem. What was to be done then? Feynman continues:

> But then, when the moon project was over, NASA had all these people together: there's a big organization in Houston and a big organization in Huntsville, not to mention at Kennedy, in Florida. You

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[5] Gillette, Robert, "Space Shuttle: Compromise Version Still Faces Opposition," in *Science* 175 [January 28, 1972], p. 393.

[6] Ibid., p. 392.

[7] Richard P. Feynman, *"What Do You Care What Other People Think?" Further Adventures of a Curious Character* , W W Norton & Company, 1988, pp. 213 - 215.

> don't want to fire people and send them out in the street when you're done with a big project, so the problem is, what to do?

Feynman describes the conflicts between the managerial ignorance (intended or unintended) on the one hand and the technical expertise of engineers on the other. He argues that these two sides did not communicate and cooperate well and resulted in such a disastrous outcome (Challenger accident). The problem, as Feynman conceives it, is "the exaggeration at the top being inconsistent with the reality at the bottom." Feynman uses some kind of "idealistic and communicative situation" to measure against the exaggeration and distortion between NASA's managerial ignorance and technical expertise. In Feynman's eyes, the problem is both social and technical. Feynman implicitly assumes an ideal situation in which the social and the technical part of space activities should cooperate in harmony. Big cheeses and managers could freely communicate with engineers at different levels in such an ideal situation!

Feynman's normative concern is surely intriguing. However, his interpretative strategy needs to be carefully refined. What is the contrast between managerial ignorance and technical expertise? There exist two critical approaches compatible with Feynman's concerns. Hereafter I would like to survey two theoretical approaches. The first approach is what I dub as humanist studies of technology. The second is conventionally called critical theory of technology. These two theoretical approaches help frame and clarify a problem statement that guides the inquiry into the NASTRAN case.

Many historians and sociologists have attempted to formulate the relations between technologies and society. Among other humanist studies of technology, Walter A. McDougall puts forward a question like this:

> Are our societies locked into irreversible technological change to the point where human institutions themselves have become "part of the machine?" Or do people, acting through politics, retain their ability to choose which future to invent, or whether to try? If so, can we and our leaders be trusted

> with such responsibility? What is the relationship between man and his machines?[8]

McDougall's question is broad in scope and moral in character. The scope of investigation is broad because it contains a historical characterization of the relationship between human agency and machines. The character is moral because McDougall emphasizes the autonomy of human agency and worries that technology would be out of human's control.

Langdon Winner, as a critical theorist of technology, elaborates McDougall's question on the aspect of the autonomy of human agency. He leaves "how various specific changes in technology have affected the course of social changes" to empirical studies, and concerns "human autonomy" and "the loss of mastery" over technology. To deal with this question, Winner analytically separates technology and society as two realms of inquiry:

> On the one hand we encounter the idea that technological development goes forward virtually of its own inertia, resists any limitation, and has the character of a self-propelling, ineluctable flow. On the other hand are arguments to the effect that human beings have full, conscious choice in the matter and that they are responsible for choices made at each step in the sequence of change.[9]

Winner intends to lay out the social and the technical as seemingly autonomous realms and emphasizes that the technical is equally significant as the social. By presenting the reciprocal interlocking process between the technical and the social, Winner also wants to deliver a critical and moral message to his readers. The subtitle of Winner's *Autonomous Technology* suggests that the formulation of his central argument emphasizes the "technics-out-of-control in political

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[8] Walter A. McDougall, *...the Heavens and the Earth: A Political History of the Space Age*, 1985, p. 11.

[9] Langdon Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*, The MIT Press, 1977, p. 46.

thought." Winner conveys this critical message by showing "how things went wrong" in the interlocking process of the social and the technical.

To some extent, Winner and McDougall both share a similar moral stance. To love or hate technology in general does not help us participate in reshaping technology or building favorite social orders. As Melvin Kranzberg argues, "technology is neither good not bad, nor is it neutral."[10] For historians like Kranzberg, any given technology should be judged by its relevant human actors in a specific context. Contemporary researchers following the humanist studies of technology, *pace* McDougall, scorn the fear of being controlled by the Machines and point out the direction that humans can decide for themselves otherwise. In this more humanistic approach, the Machines, coupled with techniques and knowledge, should be completely interpreted and manipulated by human actors. While speaking in this way, the buzzword "responsibility" pops out for the choice made in each step that human society moves. Humanists witnessed the unleashing of technological power and its disastrous outcome. They want to reclaim the human supremacy over machines.

On the other hand, to speak for technological change in terms of its broader effects centered on machines raises another set of intellectual muddles: the doctrine of technological determinism. Winner describes technological determinism as:

> Often couched in the noncommittal language of "the impact of technological innovation," the idea plays a prominent role in a great deal of contemporary writing on technology and society. One need only look at the literature on "technology assessment," "social indicators," "alternative futures" or "the year 2000" to see uncriticized quasi-deterministic assumptions at the center of speculation and research.[11]

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[10] Melvin Kranzberg, "Presidential Address, Technology and History: 'Kranzberg's Laws,'" in Technology and Culture, Vol. 27, 1986, p. 545.

[11] Ibid. p. 74.

To remedy this theoretical pitfall, we should reassert that the social and the technical run in a parallel and interconnected way. To avoid technological determinism, McDougall would probably formulates his question this way: Do machines determine the following course of human actions? Or, do humans decide which technical path to be taken? And Winner would perhaps put it this way: Should we humans gain or regain our control over technological development? Or, should we humans follow the inevitable development of technology?

These questions show a tendency humanist studies of technology. In contrast, the critical theorist Herbert Marcuse argues that technology had become a form of political domination. He argues that what Max Weber called "rationalization" realizes not rationality but rather, in the name of rationality, a specific form of unacknowledged political domination. In accordance with this rationality, the "rationalization" of the conditions of life is synonymous with the institutionalization of a form of domination whose political character becomes unrecognizable. That is to say, the technical reason of a social system does not lose its political content. Marcuse's critique of Weber concludes that

> the very concept of technical reason is perhaps ideological. Not only the application of technology but technology itself is domination (of nature and men) — methodical, scientific, calculated, calculating control. Specific purposes and interests of domination are not foisted upon technology "subsequently" and from outside; they enter the very construction of the technical apparatus. Technology is always a historical-social project: in it is projected what a society and its ruling interests intend to do with men and things. Such a "purpose" of domination is "substantive" and to this extent belongs to the very form of technical reason.[12]

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[12] Herbert Marcuse, "Industrialization and Capitalism in the work of Max Weber," in Negations: Essays in Critical Theory, with translations from German by Jeremy J. Shapiro (Boston 1968), pp. 223f. I borrowed this quote from Jürgen Habermas' "Technology and Science as 'Ideology,'" in *Toward a Rational Society: Student Protest, Science and Politics*, translated by Jeremy J. Shapiro, Beacon Press, Boston, 1970, p. 82.

This critical strategy is distinctive because (1) critical theorists focused on the social forms of science and technology, namely, social hierarchy, bureaucracy, technocracy. This form mirrors the instrumental rationality of science and technology onto a social organization; and (2) concentrated on how human actors mediate, interpret, and even manipulate scientific and technological knowledge for different purposes. Social actors constantly negotiate with each other about the meaning of artifacts until they reach a set of shared perspectives and values.

The emphasis on the fusion of technology and domination is the hallmark of critical theory of technology. However, Winner intends to balance between these two orientations, namely, the humanist studies of technology and the critical studies of technology. Nevertheless he still firmly holds on the critical stance and argues against humanist approach by emphasizing the technical aspect of the socio-technical change. This critical stance in fact invites a criticism from Donald MacKenzie. MacKenzie argues that Winner's book "still throws its weight (though not without some reservations) behind a technological determinist interpretation of Marx."[13] MacKenzie accuses Winner as a technological determinist by quoting the following passages:

> (1) Again and again in his writing Marx states that the forces of production play a determining role on human history. (2) In the language of social science, Marx has isolated *the* primary variable in all of history. (3) Further elements of determinism in Marx's theory can be seen in his view that within each historical period the social relationship found with the productive processes are a function of the forces of production existing at the time.[14]

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[13] Donald MacKenzie, "Marx and the Machine," *Technology and Culture*, Vol. 25, July 1984, p. 474.

[14] Langdon Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*, The MIT Press, 1977, pp. 78-79.

According to MacKenzie, Winner swings closer and closer to the end of technology in the spectrum of technology and society. It seems to MacKenzie that Winner still views technology as the unmoved mover in social change. In the conclusion of MacKenzie's recent book, *Inventing Accuracy*, he argues that Winner's *Autonomous Technology* remains in the camp of technological determinism.[15] MacKenzie claims that his entire book, *Inventing Accuracy*, aims to demystify "technological determinism," especially the version that describes "a technological juggernaut out of control, following its own course independent of human needs and wishes."[16] Speaking at a similar tone, Kranzberg states: "Indeed one of the intellectual clichés of our time, whose scholarly statement in the writings of Jacques Ellul and Langdon Winner, is that technology is pursued for its own sake and without regard to human need."[17]

The issue at hand becomes the issue of what technological determinism means to both MacKenzie and Winner. This in turn brings our discussion back to the autonomy of human agency. For Winner, the verb "determine" literally suggests "giving direction to, deciding the course of, establishing definitely, fixing the form or configuration of something." The mundane sense of "determine," for Winner, does not trigger disputes. Controversies on the matter, however, stem from a much broader and more dubious notion. Understood in its strongest sense, technological determinism, as Winner puts it, stands on two hypotheses:

> (1) The technological base of a society is the fundamental condition affecting all patterns of social existence. (2) Changes in technology are the single most important source of change in society.[18]

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[15] Donald MacKenzie, *Inventing Accuracy*, the MIT Press, 1990, p. 383.

[16] Ibid. p. 383.

[17] Melvin Kranzberg, "Presidential Address, Technology and History: 'Kranzberg's Laws,'" in Technology and Culture, Vol. 27, 1986, p. 545.

[18] Langdon Winner, *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought*, The MIT Press, 1977, p. 76.

On the other hand, to be a technological determinist, for MacKenzie, is to believe that in some sense "technical change *causes* social change, indeed that it is the most important cause of social change."

In short, both Winner and MacKenzie agree on the basic assumptions of technological determinism. To distance themselves from technological determinism, they deploy different strategies to read Marx in non-deterministic ways. MacKenzie emphasized the social contingency and adopted a Constructivist approach, whereas Winner tended to identify the major thrust for both the social and the technical changes occurring in each particular historical event. For example, MacKenzie argues that

> To give full weight to the first term in expressions such as "*prime* mover" and "*independent* variable," it would also have to be believed that technical change is itself uncaused, at least by social factors.[19]

MacKenzie points out that most historians and sociologists borrowed this deterministic version from Marx without noticing the latent difficulties. To reinterpret Marx, MacKenzie subsequently analyzes some shortcomings and difficulties to read Marx as a technological determinist.

To accomplish this task, MacKenzie debunks the unclear meaning and questionable autonomy of the forces of production, and to further reconstruct the meaning of the word "determine." Following the pace of Raymond Williams, he demonstrates that the verb "to determine" is linguistically complex, especially after the translation of the German *bestimmen*. MacKenzie argues that "determinism" implies powerlessness in the face of compelling external agency, derives, from the idea of determination by an authority. Consequently, "determinism" in

[19] Donald MacKenzie, "Marx and the Machine," *Technology and Culture*, Vol. 25, July 1984, p. 474.

this sense would paralyze actions.[20] On the contrary, MacKenzie suggests to consider another related but different sense of the word determination as

> A set of limits within which human agency can act, and against which it can push. It is an image fully compatible with another of Marx's great aphorisms, that people "make their own history, but they do not make it just as they please; they do not make it under circumstances chosen by themselves, but under circumstances directly encountered, given and transmitted form the past."[21]

Understood this way, MacKenzie suggests to rethink the deterministic effect of the forces of production over the relations of production, or of the relations of production over the superstructure. Namely, he reconstructs a dialectical relationship between society (social relations) and technology (force of production).

Furthermore, MacKenzie wants to identify the *contingency* where "human agency can act and against which it can push." At this point, MacKenzie allies with his forerunners and colleagues at Edinburgh. He proposes to answer the effect of social relations on technical design in this way:

> The most straightforward way of doing this hinges around documenting the *contingency* of design, identifying instances where "things could have been different," where, for example, the same artifact could have been constructed. Having identified contingency, the historian can then ask why one way, or one design, was chosen rather than another.[22]

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[20] Donald MacKenzie, *Inventing Accuracy*, the MIT Press, 1990, p. 382.

[21] Donald MacKenzie, "Marx and the Machine," *Technology and Culture*, Vol. 25, July 1984, p. 479.

[22] Ibid. p. 500.

Interestingly enough, MacKenzie adopts Winner's example of designing the bridges over Long Island parkways to demonstrate the importance of identifying contingency.[23] He also argues that David Noble's analysis of the automation of machine tools is an illustration of identifying contingency.[24]

In this thesis, both the concept of agency and technology will be considered. In so doing, I want to address Feynman's concern in a more theoretical way. Feynman considers the inconsistency between the technical expertise and management as a "big problem." The issues, after the above survey of theoretical formulations between society and technology, suggests that the technical expertise consists of a managerial and an organizational dimension and the technology always involves human intervention. Having learned from the humanist studies of technology, this thesis will seriously consider how agency intervene and reshape technology; having learned from critical theory of technology, this thesis also wants to examine the interlocking process of the social and the technical and place the outcome of this process under a critical evaluation.

I first encountered the story of NASA and NASTRAN by studying the engineering analysis called finite element analysis. The search for relevant materials of finite element analysis led me back to the contexts of aviation technology in the 1950s and 1960s. The enormous body of literature forced me to funnel the wide scope of my investigation and to concentrate on the first general-purpose finite element computer program, NASTRAN. I found the process that I have

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[23] Ibid. p. 500. Also see Winner, Langdon, *The Whale and the Reactor: A Search for Limits in an Age of High Technology*, 1986, The University of Chicago Press, Chicago & London. pp. 22-25.

[24] Ibid. p. 501. Also see David F. Noble, "Social Choice in Machine Design: The Case of Automatically Controlled Machine Tools and A Challenge for Labor," in *Politics and Society*, Vol. 8, 1978, pp. 314-347.

been through operates in a way very similar to what Harry Collins and Wiebe E. Bijker call "historical snowballing."[25] Let me attempt to describe this process.

I investigated three kinds of primary materials: NASA documents and correspondence, engineering research papers, and articles from popular science journals. I began with engineering research papers and articles from popular science journals. Most engineers refer back to a series of "pioneers" in the field of finite element analysis during the 1950s and 1960s. Most of these pioneers got involved in the aerospace computing technology. I found one book called *Early FEM Pioneers*. It gave me a good sense in terms of where to look and what had to be examined. These engineering research papers helped me follow key actors in action. While following the actors by reading historical documents, I traced relevant actors and actions by a thread that coheres and makes sense of the story of NASTRAN. Subsequently those new actors and actions are also followed. This methodological model serves primarily to argue that there is no essential problem involved in using the concepts actor and action in empirical studies of technology.

After my arrival at the National Air and Space Museum (NASM), I focused on the collection of NASA documents and correspondence. NASM contains many NASA documents. Again, by historical snowballing, I trace several NASA actions during the late 1960s and early 1970s regarding NASTRAN. More importantly, I obtained a chance to drive to Langley where NASTRAN was maintained and the NASTRAN office was located. At Langley, the Record management still have correspondence in microfilm between the NASTRAN office and other aerospace users. At that time, I already had many names and events in mind ready to search for them accordingly. NASA's documents and correspondence helped me fill in several blanks while reading engineering research papers and articles.

The next chapter describes the central concern of computation among aerospace engineers and the genesis of NASTRAN project. Chapter three details the process of maintaining,

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[25] Bijker, Wiebe E. and Law, John. *Shaping Technology / Building Society: Studies in Sociotechnical Change*. 1992. Cambridge, MA: MIT Press, p. 77.

improving and rewriting NASTRAN, the intervention of NASA Headquarters and the resistance of the automotive users. Chapter four reflects on some issues discussed in this chapter.

Chapter 2

Selecting a Technology in the Crisis of NASA's Political Legitimacy

The computing methods in solving airframe problems emerged around World War II. The major thrust for developing computing methods directly linked the increasing speed of aircraft. Beginning with World War II, aerospace engineers designed aircraft to fly faster and faster. The top speed of aircraft increased in the 1940s until it reached a bottleneck: aerospace engineers named it the sonic barrier. As aerospace engineers finally surmounted the sonic barrier, airframe problems became more complex and required a prodigious number of calculations. One Northrop engineer described the scene in the workplace as follows: “Try to imagine a room full of engineers, designers, and computation personnel, stretching as far as the eye could see, all operating adding machines, desk calculators, and comptometers. That was the aerospace computing center in 1945.”[26] This image shows that the solution of airframe problems required many people and much effort in the 1940s. After World War II, aerospace engineers began a search for computing methods to meet the requirements of airframe problems.

There were two sets of significant airframe problems in which aerospace engineers examined to determine how an airframe fails to bear loads. These two sets of problems were “buckling” and “flutter;” each of them related to a specific configuration of airframes. Aerospace engineers separated these two sets of airframe problems in terms of “shells” and “wings”

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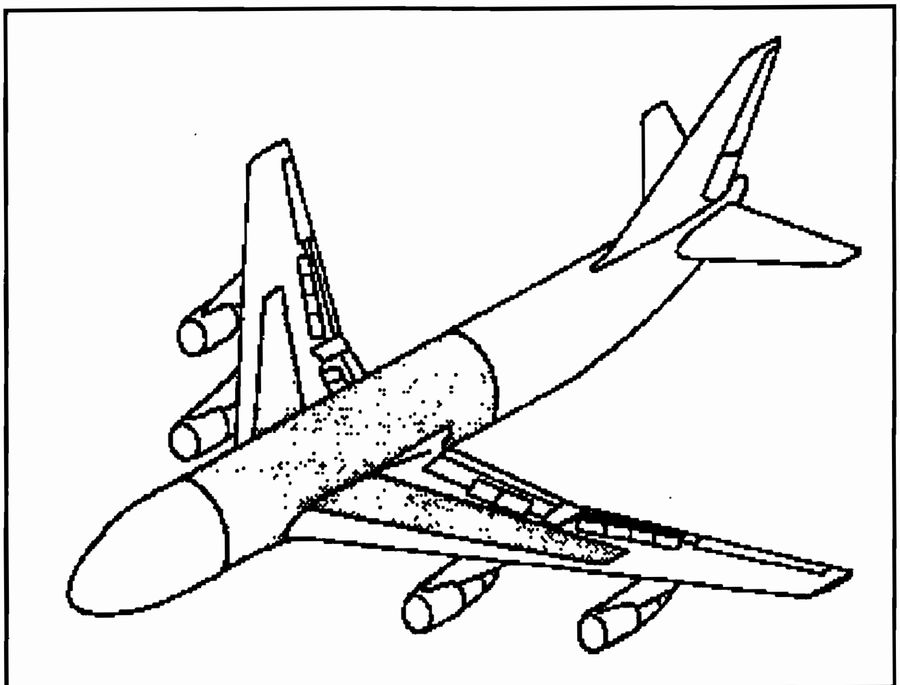
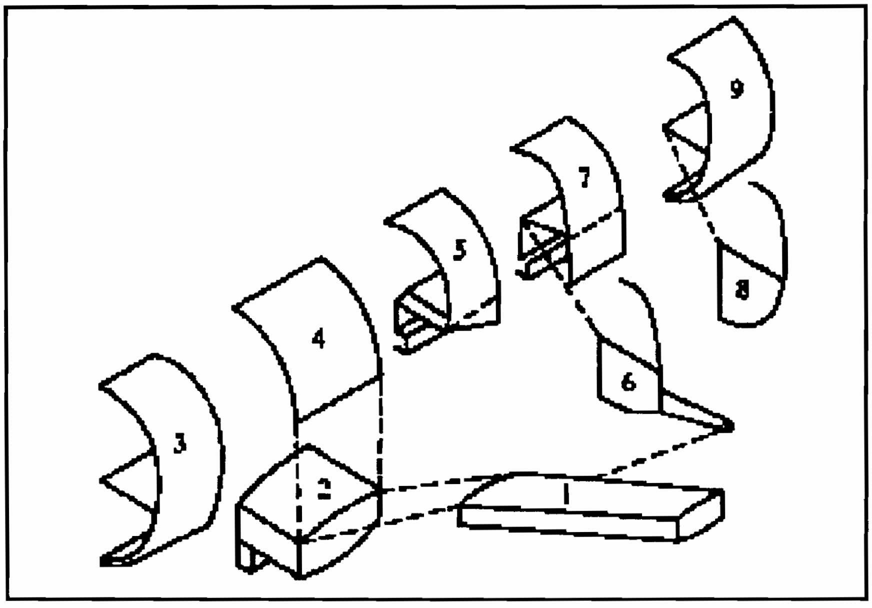
[26] I borrow this quote from Paul Ceruzzi's *Beyond the Limits: Flight Enters the Computer Age,* MIT Press, 1989, p. 33.

Figure 2. The Shells and Wings of Boeing 747 and its Finite Element Modeling



a. Boeing 747 Aircraft. (Cross-hatched area indicates portion of the airframe analyzed by finite element method.)



b. Substructures for finite element analysis of cross-hatched region.

Shells could be the body of a launching booster or the fuselage of an jet plane, whereas wings could have various shapes to be considered, such as delta wings. Due to their different geometric and physical conditions, aerospace engineers classified different airframe problems. The first set of airframe problems were derived from shells and the second from wings.[27] In most cases, the shell part of an airframe had problems of what engineers call buckling; and the wing part had those of flutter.

The problems of flutter appeared more difficult and urgent to aerospace engineers. As the speed of aircraft increased, aerospace engineers encountered a particular aerodynamic situation in design. In the case of flutter, consider the swaying of a suspension bridge. A breeze makes the bridge swing. If the frequency of the breeze resonates with the natural frequency of the bridge, then the amplitude of bridge's oscillation becomes greater and greater until catastrophe results.[28] The wings of aircraft encounter a similar condition while flying. When aircraft fly at a certain speed, the natural frequency of wings resonates with the frequency of aerodynamic forces. Aerospace engineers therefore formulated the vibration problems of wings as "flutter." Around the 1950s, the problems of flutter appeared more acute and urgent when the flight of aircraft went through both "subsonic and supersonic zones." To provide solutions, aerospace engineers needed a special field of knowledge to deal with these problems.

Aerospace engineers named this special field of knowledge and practice to solving airframe problems as "structural analysis and design." It provided analytical and numerical tools for aerospace engineers. These tools helped engineers to deal with the increasing complexties in formulating the mathematical model of airframe problems. To formulate the mathematical model, aerospace engineers identified a particular part of airframe to be analyzed, and then modeled this

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[27] See Richard F. Hartung, "An Assessment of Current Capability for Computer Analysis of Shell Structure," in *Computer and Structures*, Vol. 1, pp. 3-32, Pergman Press 1971.

[28] For a graphic image, see Paul E. Ceruzzi, *Beyond the Limits: Flight Enters the Computer Age*, The MIT Press, 1989, pp. 33-37.

part of airframe as an assembly of idealized "structural elements," such as beams, girders, columns, plates, and shells. For each structural element, traditional engineers had a variety of “classical solutions.” However, for a complex airframe, these “classical” solutions did not seem to work because aerospace engineers could not model a complex structure simply by the combination of simple structural elements.

Structural analysis and design also involved mathematical puzzles. Mathematicians provided two means of achieving possible solutions: analytical and numerical. After selecting an idealized model of a given a structure, aerospace engineers began to borrow some "mathematical tools" to get solutions from models of airframes. Models of airframes were put down in mathematical expressions. These mathematical expressions usually contain some differential equations characterizing the motion and location of an airframe, and boundary conditions providing specific constraints in terms of time and space. To get analytical solutions, engineers solve their mathematical model by following rigid logical steps until they reach an “exact solution.” In contrast, the numerical solution means that engineers borrow other mathematical tricks to “approximate” the exact solutions. Furthermore, aerospace engineers obtain numerical solutions by engineering methods. These methods require not only the mathematical knowledge to model the airframe but also the incisive engineering intuition to diagnose. To some extent, engineering intuition comes first. As one senior aerospace engineer once told me, “I don’t give a damn to mathematics if it cannot help me out!”[29] This attitude indicates how aerospace engineers prioritize their intuition rather than mathematical analysis.

"The matrix approach” as an engineering method solves airframe problems. In Structural analysis and design, aerospace engineers usually used a set of differential equations to describe their model.[30] Engineers also characterize the types of problems and solutions they

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[29] Interview with Dr. Howard Wolko in the National Air and Space Museum on June 20, 1993.

[30] For a detailed discussion of major airframe problems in 1960s, see a collection of conference essays, *Structure for Space Operations*, NASA, Washington D. C., December 1962, Office of Scientific and Technical Information. This

constantly work on. For example, some pairs of concepts include static versus dynamic, linear versus non-linear, and stable versus unstable. Statics and dynamics distinguish whether the structure itself is in motion. A structure deforms in a linear way means that the deformation is proportional to the external forces exerted on it. A structure is stable means that the structure is in equilibrium of forces over a long period of time. For an example of buckling in statics, take an aluminum can and then step on the top of it. You see how the can "buckles" under the pressure exerted by your foot. In this case, the can remains still while you step on it. Hence, engineers consider this load condition as the ideal model in statics, which implies a study of airframe without motion. For an example of buckling in dynamics, consider a (launching) booster. When a booster launches, the shell structure of the booster vibrates. Aerospace engineers consider this condition as the ideal model in dynamics, which implies a study of the airframe in motion. A dynamic model includes more variables into considerations; therefore, the mathematical modeling will be more complex.

Besides mathematical tools, aerospace engineers began using computing machines to solve airframe problems in the 1960s. The power of this new tool has been dubbed "revolutionary" and a "major breakthrough." For example, Ray W. Clough, a young engineering professor at Berkeley, joined the Boeing Summer Faculty Program to study airframe problems in 1952. Boeing organized research projects like this to hire young engineering professors from all over the country. Clough worked with the head of the Structural Dynamics Unit, M. J. Turner.[31] In the late 1950s, Turner and Clough developed a "matrix technique" recognized as a practical computing method to solve airframe problems. The matrix technique buried in Turner and Clough's paper later became recognized by aerospace engineers. Turner and Clough's paper

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NASA-University conference, conducted on November 1-3, 1962, was held to "provide an authoritative and up-to-date review of aeronautical and space science technology."

[31] Clough, R. W., "Original Formulation of the Finite Element Method, in *Finite Elements in Analysis and Design* 7 (1990), p. 91.

demonstrated that the computing speed of the matrix approach on machines could far exceed that of solving airframe problems by hand. Many aerospace engineers marked this paper as the beginning of the implementation of computer programs using the matrix approach in many places in the United States.[32]

To exploit these computing machines by a body of technical knowledge, engineers gradually developed "a method." This method had to take advantage of both the mathematical tools and computers simultaneously. As a result, this method operates on the basis of linear algebra (matrixes) and contained mixed characters of both computing algorithms and numerical analyses. Most engineers called it "the matrix approach" during the 1960s. The matrix approach in the 1960s invoked different disciplinary understandings of airframe problems and it became an interdisciplinary niche later characterized as "finite element methods" or "computational mechanics." More importantly, engineers regard the matrix approach as a "technological base" for a powerful tool—NASTRAN.

The matrix approach embedded in the NASTRAN computer program was an examplar of engineering methods. I will demonstrate the matrix approach as an examplar of engineering method and point out two different engineering interpretations of it. First, to show the matrix approach represents a typical case of engineering method implies that the matrix approach combines both mathematical modeling and engineering interpretation. For a complex airframe, the basic approach is to consider the airframe to be an assemblage of small, manageable members or elements. In this analytical technique, aerospace engineers have two options for choosing unknown variables in their mathematical expressions. These two kinds of variables are the displacements (and rotations) of the joints and the forces (and moments) applied on the joints. Given the chosen variables of unknown values, aerospace engineers could plug them into derivative strategies of structural analysis, with some initial and boundary conditions of the airframe.

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[32] Interview with Dr. Howard Wolko in the National Air and Space Museum on June 20, 1993.

The matrix approach in structural analysis and design used the following procedure to accomplish the computational task. Aerospace engineers considered a complex airframe to be an assemblage of small "members or elements" that could be modeled mathematically by their shape. For each "member" of the airframe considered by itself, aerospace engineers can obtain from structural mechanics the algebraic equilibrium equations that relate displacements and forces at the end of each member. For example, consider a bar. Under the idealized assumptions of aerospace engineers, the bar member can only bear tension or compression. Hence, the displacement of a bar member means it either elongates or shortens under the exertion of tension or compression. Because all members meeting at a joint must have the same displacement at that joint, the equations for the several members can be combined to give *one large set of algebraic equations* for the structure as a whole. The external forces are introduced as equivalent joint loads. Once all the joint displacements are known, the equations for the individual members can be used again to obtain the forces and stresses anywhere in the airframe.[33] The crucial element in the above description is the matrix form of the large set of algebraic equations; therefore, aerospace engineers call it "the matrix approach" (see Figure 3).

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33 Mark, R., Chiu, J. K., & Abel, J. F., "Stress Analysis of Historic Structures: Maillart's Warehouse at Chiasso", in *Technology and Culture*, (January, 1974), Vol. 15, No. 1, p. 61.

Figure 3:

In the most simplistic case, aerospace engineers usually have one large set of algebraic equations as follows:

$$
\begin{gathered}
a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + a_{14}x_4 + \ldots + a_{1n}x_n = b_1 \\
a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + a_{24}x_4 + \ldots + a_{2n}x_n = b_2 \\
. \\
. \\
a_{m1}x_1 + a_{m2}x_2 + a_{m3}x_3 + a_{m4}x_4 + \ldots + a_{mn}x_n = b_m
\end{gathered}
$$

This set of algebraic equations can be written in the following matrix form:

$$\mathbf{Ax} = \mathbf{b}$$

where the coefficient matrix $A = \left[a_{ij}\right]$ is the m by n matrix:

$$
\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \ldots & a_{1n} \\ a_{21} & a_{22} & \ldots & a_{2n} \\ . & . & \ldots & . \\ a_{m1} & a_{m2} & \ldots & a_{mn} \end{bmatrix} \quad \text{and} \quad \mathbf{x} = \begin{bmatrix} x_1 \\ . \\ . \\ x_n \end{bmatrix}, \quad \mathbf{b} = \begin{bmatrix} b_1 \\ . \\ . \\ b_m \end{bmatrix}
$$

The following paragraphs will recount the birth of NASTRAN and emphasize two engineering mechanisms of the matrix approach both embedded in NASTRAN. The first of these two mechanisms is the configuration of different "structural members," or "elements." For each "structural element" considered by itself, aerospace engineers are able to model the structural elements mathematically in a (Cartesian) coordinate of relatively small scope. Aerospace engineers model some "element prototypes" mathematically as the basic units to build up a model for the entire aircraft, which is in turn measured by a (Cartesian) coordinate of relatively big scope. These elements could be as simple as bars, beams, or plates. For a computer program of structural analysis and design, the more element prototypes with which it is equipped, the more flexible it becomes. The second one is to define some specific operations that requires some "rigid formats" to be built in the computer program. These rigid formats serve as a library of functions which can be "called upon" by aerospace engineers in various analytical function of NASTRAN.

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Many aerospace companies were developing computer programs by exploiting the matrix approach. Aerospace engineers called them matrix computer programs. NASA decided to contract a team developing its own matrix program. Several protagonists were involved in this development: NASA Headquarters, Goddard Space Flight Center (GFSC), the NASTRAN office in Langley Research Center (LRC), NASTRAN contracting developer, aerospace and automotive users. Among them, the major player, NASA Headquarters became more involved after NASA had a crisis of legitimacy.

NASA Headquarters decided to develop its own matrix program rather than to use or expand existing ones. For example, James Webb, the Director of NASA Headquarters from 1961 to 1968, defined the coordination of Project Apollo's many constituent teams as preventing them from flying off in their own directions, yet somehow providing flexibility that Centers and contractors need to perform with imagination. Since 1961, NASA Headquarters had attempted to established overall management strategies. First, NASA somehow cut through the traditional layers of bureaucracy so that high-level attention could be brought to bear quickly on local programs. Second, NASA endowed individuals with the responsibility to oversee and direct all activities related to given missions wherever they might be taking place. Third, NASA relied on systems integration: the administrative art of conceiving a whole, breaking it into subsystems, nursing along the R & D, testing, and evaluation of each, like a cook with six dishes on the stove, and finally making sure that each interfaced properly with all the others when time came to put the meal on the table.[34]

NASTRAN would provide a technical channel to bring together various NASA centers. NASA Headquarters later endorsed NASTRAN as "a unified means" for coordination. While implementing NASTRAN, NASA Headquarters presented NASTRAN as a solution of its coordination needs. On February 22, 1968, Dr. Hermann H. Kurzweg, Director of Research in NASA Headquarters, addressed the House of Representatives Subcommittee on Advanced Research and Technology, as part of the 1969 NASA Authorization hearing. In his testimony, Kurzweg emphasized the benefits and contributions of the NASTRAN computer program to NASA Centers and contractors for designing space vehicles. Kurzweg argued:

> [T]his new program called NASTRAN will provide a new and greatly improved coupling between various stage and system analyses. The program will provide a unified means for readily communicating to all organizations concerned structural information such as stress, deflections, vibration frequencies and amplitudes, and other data and will thereby eliminate the necessity for each organization re-analyzing

[34] Walter A. McDougall's "Chapter 18, Big Operator: James Webb's Space Age America" in *...the Heavens and the Earth: A Political History of the Space Age*, 1985, pp. 376-377.

several parts of the structure, thus saving substantial amounts of effort and money.[35]

Therefore, the NASTRAN computer program became a “unified means” to coordinate many organizational dimensions of airframe problem, such as saving effort and money, reduce re-analyzing, and transferring data.

On the other hand, NASA also had to organize different disciplinary knowledge into proper sectors in engineering analysis and design. This was to take account of disciplinary specialization and division of technical labor. During the 1960s, solving airframe problems by using matrix computer programs implied a complex amalgam of technoscientific knowledge supported by a computational infrastructure. The buckling of shells or the flutter of wings required a body of knowledge called, variously, "analytical mechanics," or "rational mechanics" or sometimes "applied mechanics" to identify specific airframe problems. To solve airframe problems of these kinds entailed many numerical techniques to code engineering problems into computer programs. The computation of airframe problems by using these numerical techniques could not avoid a prodigious number of calculations. Hence, the computing support became significant. For aerospace engineers, this complex amalgam of technoscientific knowledge did not count if it could not get things done.

As I have indicated in the Introduction chapter, NASA experienced a crisis of its legitimacy. NASA Headquarters came to terms with this crisis by seeking new sources of legitimacy and trying to serve new constituencies. The following paragraphs describe how NASA Headquarters justified NASTRAN as a way of coordinating aerospace work at three different centers and reaching out to new industries.

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[35] 1969 NASA Authorization, Thursday, February 22, 1968, House of Representatives, Committee on Science and Astronautics, Subcommittee on Advanced Research and Technology, Washington, D.C.

At the annual review of NASA's research program in January 1964, Douglas Michel of NASA Headquarters chaired the section on airframe problems.[36] In the discussion on computing, many of the NASA Centers wanted to develop computer programs for analysis and design of airframes to meet each Center's particular need. Douglas Michel suggested that perhaps a "single program" could meet all the Centers' needs. This idea seemed very attractive. Thomas G. Butler, supervisor of the NASTRAN project in the Goddard Space Flight Center, advocated:

> To make things go smoothly it would be well to anticipate such an overall analysis so that the interface compatibility conditions could be provided for in advance of the final analysis. General Purpose programs [NASTRAN] which are adaptable to many computers can provide this communication vehicle.[37]

From NASA Headquarters' point of view, one single computer program could reduce repetitive computations and double-checks between Centers, and eliminate difficulties when transferring computing data. This work required more coordination.

NASA Headquarters appointed an ad hoc committee with representatives from eight NASA Centers to study the possibility of developing NASA's matrix program.[38] After six months of investigation, the "Ad Hoc Committee on Computer Methods in Structural Analysis" reported to Headquarters that there was no computer program developed by aerospace companies that "had broad, uniform capabilities in the three interdependent disciplines of analytical

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[36] *Final Report for NASTRAN Project*, prepared for Goddard Space Flight Center, Greenbelt, Maryland, March 2, 1970, Contract No. NAS5-10049, prepared by Computer Sciences Corporation, Los Angels, California. I found this document from the collections in the National Air and Space Museum under the financial aid of the Smithsonian Fellowship program.

[37] T. G. Butler, "On the Reduction of Proliferation of Finite Element Programs," in *NASTRAN Users' Experiences*, NASA TM X-2378 Volume II, D.C., September 1971, p. 821.

[38] *Final Report for NASTRAN Project.*

mechanics, numerical methods and computer programming."[39] NASA decided to contract a team supervised by Goddard Space Flight Center (GSFC). Furthermore, to ensure "interdisciplinary efforts," NASA particularly encouraged "teaming" among contractors. This means that the departmentalized tasks should be able to cooperate with each other under the line-staff principle. NASA Headquarters chose two teams to prepare the so-called "Technical Evaluation Reports." These teams were competing for the contract. One team was headed by the Computer Sciences Corporation (CSC) and augmented by the MacNeal-Schwendler Corporation and the Martin Company. The other team was headed by Douglas Aircraft and augmented by Bell Aerosystems, Philco Ford, and the Computer Usage Corporation. Eventually, NASA selected the CSC team to begin development on the program.[40]

This contract was soon dubbed "the NASTRAN project" by NASA and the CSC team. The CSC team was the contracting developer. During the Apollo years, NASA worked intimately with aerospace companies solving airframe problems by matrix computer programs. For example, Boeing provided computing support for NASA to solve airframe problems because it was one of NASA's primary aerospace contractors. NASA also supplied aerospace contracting dollars for Boeing's benefit. Since the early 1960s, the financial abundance of the Apollo program bolstered the contracting link of computing support between NASA and other aerospace firms like Boeing. According to DOD and NASA's *Incentive Contracting Guide*, one special type of contract was designed for "use in research or exploratory development when the level of contractor effort required is unknown."[41] This type of contract is called "Cost-Plus-a-Fixed-Fee (CPFF)." This term means that "the Government agrees to reimburse the contractor for all allowable and allocable costs incurred in performance of the contract; in addition, the Government

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[39] *Final Report for NASTRAN Project.*

[40] Ibid.

[41] See *Incentive Contracting Guide*, published by Department of Defense and National Aeronautics and Space Administration in October, 1969.

agrees to pay the contractor a fixed number of dollars above the cost as fee (profit) for doing the work."[42] Compared to other types of contracts, the Cost-Plus-a-Fixed-Fee allows the contractor to pursue or explore whatever is needed in its "scientific venture" in a very flexible way. The settings of contract made possible that NASA and DOD could mobilized tremendous resources and aerospace firms to work together during the Apollo years.

With this kind of contracting relationship between NASA and aerospace companies and universities, NASA at first borrowed matrix computer programs from aerospace companies for its Apollo mission. There were many computer programs in different aerospace companies and universities that NASA could access for its computational needs. For example, Pedro Marcal at Brown University; Ray Clough at University of California, Berkeley; Richard Gallagher at Cornell University; F. DeVuebeckes at University of Liege; Theodore Pian at MIT; and John Argiris at University of Stuttgart all developed their own computer programs for solving airframe problems in the late 1960s. Aerospace companies also developed their in-house computer programs at the same time for NASA's contracting activities, including the MAGIC of Bell Aerosystems Co., the DEMON of Douglas Aircraft Co., the DAISY and FAMAS of Lockheed Aircraft Corporation.[43]

The NASTRAN project developed through the Research and Development (R&D) "incentive contracts" of the ascendant Apollo project around the mid-1960s. During this time, NASA dramatically increased the amount of its contracting activities. The embodiment of the NASTRAN project within the Apollo project had its significance in computing infrastructure as well as in finance. NASA spent more than 3 million dollars in the NASTRAN project.[44] If compared to the Apollo R&D contracting fund of 1,200 million dollars in 1965, the NASTRAN

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[42] Ibid., p. 37.

[43] T. G. Butler, "On the Reduction of Proliferation of Finite Element Programs," in *NASTRAN Users' Experiences*, NASA TM X-2378 Volume II, D.C., September 1971, pp. 813-825.

[44] *NASA News*, released on February 27, 1972, by Donald Zylstra, p. 3.

project seemed only a very small piece of the cake. It had only 0.25% of the Apollo R&D budget.[45] However, it was not possible for other aerospace companies to develop such a big computer program without gigantic financial support and the computing infrastructure. Compared to other aerospace companies, NASA's contracting team became a leading developer of matrix computer programs.

NASA began releasing the NASTRAN computer program soon after the close of the Apollo years. In 1970, NASA established the NASTRAN System Management Office (NSMO) to maintain the NASTRAN computer program (hereafter the term "the NASTRAN office"; this term replaced NSMO, much of the correspondence by aerospace engineers). NASA Headquarters designated the NASTRAN office to "manage," "maintain" and "improve" the NASTRAN computer program.[46] The NASTRAN office was an executive office located in the Langley Research Center. It carried out an agenda determined by its supervisors at Headquarters.

NASTRAN attracted an enormous number of users when the NASTRAN office distributed NASTRAN into aerospace automotive industries. The NASA-sponsored Computer Software Management and Information Center (COSMIC) released NASTRAN at the average cost of $1700 for a complete set of tapes and documents, depending on the options required by the users.[47] More than 70 industrial firms, universities, and laboratories used NASTRAN after it was released. These organizations included Bell, Boeing, Fairchild, Ford Motor, General Dynamics, Georgia Tech, Grumman, Hercules, Itek, JPL, Johns Hopkins U., Lockheed, McDonnell Douglas, NASA Centers, Navy, North American Rockwell, Northrope, Pratt & Whitney Aircraft, Sperry Rand, Teledyne, and Westinghouse. These organizations applied to

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[45] *Apollo Executives Meeting Proceedings*, January 28, 1965, pp. III-4 - 6. This document remained confidential until 1977.

[46] NASTRAN Newsletter, August 20, 1971, No. 1, p. 1.

[47] Joseph M. Carlson & Judson O. Harrison III, "NASTRAN: A Preliminary Discussion of User Impacts," in *Journal of Aircraft*, Vol. 10, No 2 [February 1973], pp. 65-66.

NASTRAN to work on aircraft fuselages, wings and tail assemblies; automobile frames and other motor vehicle components; high speed railroad tracks; turbo engines; and space vehicles and related launch facilities.[48] The wide spread of NASTRAN users was significant because NASTRAN users had a wider variety of technical orientations than NASA wanted to cover.

In this chapter, I have introduced the airframe problems as the central concern of aerospace engineers, the matrix approach as the engineering method of the NASTRAN computer program, and Headquarters' coordination of NASTRAN as a way of providing new legitimacy. Things changed after NASTRAN had been developed. The next chapter will describe how the maintenance of NASTRAN triggered both the technical and the organizational change at the same time.

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[48] *NASA News*, released on February 27, 1972, by Donald Zylstra, pp. 1-7.

Chapter 3

Coordinating NASA Centers by Rewriting NASTRAN

The users of NASTRAN attempted to maintain NASTRAN for their needs. This chapter describes some conflicts and consequences in the process of maintaining, improving, and rewriting NASTRAN between these users. To begin with, I will investigate a supervising committee of NASTRAN. NASA Headquarters organized one committee to supervise the NASTRAN Office. This committee was "the NASTRAN Advisory Group (NAG)." It contained a group of representatives from different Research Centers. The members of NAG met periodically to prioritize the necessary changes of NASTRAN and to provide common computing goals at each Research Center.[49] The membership of this committee included four members from NASA Headquarters in Washington D.C., nine from Langley Research Centers (one of whom was the Director of the NASTRAN office), one from Marshall Space Flight Center, and three from Ames Research Center.

The members of NAG convened in 1973 and classified NASA's computer programs in terms of how to set computing priorities. This classification was significant because it demonstrated in which categories the managerial staff of NASA Headquarters understood their computer programs. The report of NAG's meeting recorded three categories:[50]

Class I	Developed for in-house use. Not generally available.

[49] Memorandum, pp. 7-10.

[50] Memorandum, p. 3.

Class II	Developed, documented, and available for general dissemination. No maintenance plan for user community. (ATLAS[51])
Class III	Developed, documented, and maintained for computing machines of *selected user community*. (NASTRAN, FLEXSTAB[52])

This classification appeared as a managerial strategy of NASA Headquarters. In this managerial strategy, NASA Headquarters planned to control and supervise the accessibility of NASA's computer programs. The accessibility, as far as NASA Headquarters' concern, implied how much more money NASA needed to invest on maintaining, improving, and rewriting NASTRAN. In this chapter, I will describe the increasing intervention of NASA Headquarters as a result from the conflicts in the process of rewriting NASTRAN.

NASTRAN was in the Class III. That is to say, NASTRAN should be accessible for a "selected user community." NASA Headquarters was cautious about the rationale of its classification. According to the report of NAG's meeting, the definition of "maintenance" was the "correction of program and documentation omissions and errors and up-dating to keep operational on hardware of user community." This definition implies that maintenance "requires a commitment of yearly resources beyond completion of development." Again, from managerial perceptions, this task of maintenance appeared troublesome but necessary. More intriguingly, the report followed by such a warning: "Before a program is selected to be included in Class III, it should be understood that it will require a larger investment in contract dollars and in-house manpower to provide the maintenance function that continues beyond the completion of the development. Therefore, careful consideration should be given before categorizing it as Class

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51 ATLAS is a design program embodying structurally oriented disciplines that was used in Langley but developed by Boeing.

52 FLEXSTAB is a aero-elastic computer program in Ames Research Center. The emphasis is mine.

III."[53] The definition of "maintenance" by NASA Headquarters therefore implied three inter-related things: a selected user community, the scarcity of the resource and a technical commitment.

In the post-Apollo years, NASA Headquarters had two major roles to play: it was both a major space agency and a public benefactor. For its public image, NASA Headquarters presented itself as a government agency which resolves competing interests. More significantly, the Technology Utilization Office in NASA Headquarters constantly advocated the splendid spin-offs of NASA's space technology to the public media and Congress. NASTRAN was one of those "successful spin-offs" presented by Technology Office because NASTRAN benefited "the general public." For example, Richard L. Lesher, the assistant administrator for Technology Utilization Office in NASA Headquarters advocated NASA's contributions as a public benefactor in his statement of the 1969 NASA Authorization hearing addressed to the House of Representatives Subcommittee on Advanced Research and Technology:

> [T]he National Aeronautics and Space Administration has, as you know, been conducting a vigorous experimental program to bring about the multiple use of the new knowledge gained as a result of NASA activities. By encouraging the utilization of this knowledge in non-aerospace endeavors, an additional return is derived from the public investment in aerospace research and development.[54]

For the so-called "non-aerospace endeavors," Lesher mentioned a plethora of examples. Among those, NASTRAN was what Lesher had particularly emphasized:

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[53] Memorandum, p. 3. Several sentences are poorly constructed in this memorandum. I chose to preserve how it looks in the original NASA document.

[54] 1969 NASA Authorization, Thursday, February 22, 1968, House of Representatives, Committee on Science and Astronautics, Subcommittee on Advanced Research and Technology, Washington, D.C.

> This program [NASTRAN], now available to the public through the Technology Utilization program, has a variety of additional current and potential uses. For example, the University of California at Los Angles is using it for brain studies to determine pathological responses and analysis of normal and abnormal behaviors through brain reactions in animal subjects. A chemical company has found the program helpful in problems of input/output of driving flows, temperatures, and concentrations as related to pumps, turbine fans, blending equipment, and other machinery. The program is also expected to find application in oceanography for underwater noise studies and surface wave studies, in earthquake prediction, in analyzing vibration and wind factors for bridge construction, and for other purposes.[55]

The 1968 NASA Authorization hearing manifested the important tactic by which the space agency justified its activities to Congress. Lesher advocated NASTRAN's potential for spin-offs capable of benefiting society in a valuable and short-term way. Those important spin-offs that Lesher emphasized were indeed trivial, but this important tactic did help NASTRAN to be classified as a "public computer program."

However, regarding the classification of computer programs in the "inner document," managers in NASA Headquarters could be a bit more "honest." Hence, the Class III computer programs, of which NASTRAN was the most important, required a selected user community. Two questions emerged immediately. Who should be included in the selected user community? Who should do the selecting? To answer these two questions, we need not presume a central authority which lurked behind and made all decisions. More importantly, these two questions can be answered by describing the same process, the formation of a user community and the making of decisions. This process will not only involve the social conflicts between users' interests but also decided by the users' needs of NASTRAN. This formation process began with a controversy. The controversy over NASTRAN centered on whether NASA should implement

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55 Ibid.

more "functional modules" and "rigid formats" into NASTRAN or produce more prototypes for structural elements. As indicated in the last chapter, the two engineering mechanisms of NASTRAN formed controversies in both political and technical ways.

Different users of NASTRAN had their problems to be solved. Although there existed little agreement on which rigid formats should be made, most aerospace users wanted more needful rigid formats. The rigid formats were, in short, one kind of special design in the Direct Matrix Algebra Program (DMAP) of NASTRAN. DMAP means a sequence of operations in solving specific airframe problems. Aerospace users constantly proposed the implementation of rigid formats. For example, the NAG report targeted flutter as an important problem. NASA Headquarters suggested that the NASTRAN office survey and collect opinions from aerospace users to attack the problems of flutter:

> The requirement for flutter capability in NASTRAN is not clear. The large companies run to extremes from wanting no flutter capability to wanting both subsonic and supersonic [flutter] capability. The recommendation was accepted conditionally and largely will get a firm opinion from users as to whether or not flutter capability should be included in NASTRAN.[56]

According to this passage, the rigid formats for solving flutter problems depended on which kind of flutter problems. The flutter problem could be subsonic or supersonic. After World War II, aerospace engineers searched for computational methods for the development of aviation technology. Historians of technology see this development as a quantum leap due to the co-evolution of jet engines and wing structures. This leap occurred in aviation technology from subsonic to supersonic aircraft creating new problems in both analysis and design. What kind of flutter problems depended on the speed and the structural shape of aircraft.

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[56] Memorandum, p. 3.

The speed of aircraft distinguished the supersonic and subsonic aerodynamic forces, whereas the shapes of airframes caused different load situations for the aircraft. For example, the special features of wings are mainly swept wings with low aspect ratios. These features enable the aircraft to stay in the so-called "Mach cone." Problems of wing structures especially complicated the design of supersonic aircraft for structural engineers. To understand the relations between wing structures and aerodynamics, let me explain several technical terms at this point. Engineers define the Mach number, M, as the ratio of the air-flow speed, V, to the local speed of sound, c. Therefore the formula can be written as: $M \equiv \frac{V}{c}$. When M is larger than one, the aircraft goes supersonic. The propagation of sound waves forms a moving impact on wings. Engineers call this sound wave Mach cone. At Mach numbers larger than one, structural engineers design thin wings of low aspect ratio, or wings with enough sweep to stay within the Mach cone. However, both low aspect ratio wings and swept wings are difficult to analyze under the Mach cone. In structural engineering, the wing structures were characterized by deflections in both the chord wise and span wise directions. The problem is that the deflection analysis of such wing structures could not be conducted reliably using existing methods of analysis.

The knowledge that substantiates structural analysis and design is aero-elasticity. Engineers idealize engineering structure into several kinds, including rigid, elastic and plastic body. The rigid body does not deform at all when it bears load or moves. The elastic body only deforms in a certain proportion when it bears load or moves. The deformation is always proportional to the exerted forces. If that is not the case, then engineers call it a plastic body. Another pair of terms to distinguish the elastic from plastic body are linear and non-linear, which refers to the relations between deformation and exerted forces. Aero-elasticity is a field for solving airframe problems and the flutter of aircraft was considered as part of aero-elasticity problems.

Who cared about these flutter problems? NASA Headquarters did because they were presenting a proposal to Congress commencing the Shuttle project in the early 1970s. NASA Headquarters did not want Congress to consider NASA as an incompetent aerospace agency.

Aerospace users also cared because most of them were contractors or would-be contractors of the Shuttle project. Both NASA Headquarters and aerospace users cared about flutter problems and demanded a field of knowledge to deal with flutter problems. In particular, aerospace users required to implement more rigid formats resolving their urgent needs. To enhance the relationship between NASA and aerospace users, NASA Headquarters held a "NASTRAN user colloquium" at Langley Research Center annually starting in 1971. On September 13-15, 1971 at the first NASTRAN user colloquium, the MacNeal Schwendler Corporation initiated a project named "A Design Study for the Incorporation of Aero-elasticity Capability into NASTRAN" decided to cooperate with NASA Langley Research Center. The MacNeal Schwendler Corporation reported:

> It is expected that aero-elastic capability will be implemented in NASTRAN by a number of different rigid formats with names such as "Divergence," "Flutter," and "Frequency Response" that correspond to different types of analysis.[57]

MacNeal-Schwendler, with an aggressive attempt to become a maintenance contractor of NATRAN, proposed to amend NASTRAN by providing different types of rigid formats in solving airframe problems. Divergence, flutter and frequency response are types of mathematical modeling in solving airframe problems. The MacNeal Schwendler Corporation continued:

> The first task, before discussing the proposed measures for including aero-elasticity in NASTRAN, is to classify aero-elastic problems according to type of solution. The classification will be separated, for convenience, into static aero-elastic problems, flutter, and dynamic response problems.[58]

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[57] Robert L. Harder, Richard H. MacNeal, Robert V. Dogget, " A Design Study for the Incorporation of Aeroelastic capability into NASTRAN," in *NASTRAN: Users' Experiences*, NASA TM X-2378 Volume II, Washington, D. C., September 1971, pp. 779-795.

[58] Ibid.

The MacNeal Schwendler Corporation turned out to be the selected maintenance contractor in 1973. All three of idealized types of solutions proposed by the MacNeal Schwendler Corporation, that is, static aero-elastic problems, flutter, and dynamic response problems, could be derived from the specific modeling of airframe problems. Aerospace users equipped a set of rigid formats (similar to "subroutines" or "modules" in computer programming) to transform this specific modeling into a set of specific procedures. There were many different models of airframe problems that demanded many different rigid formats.

Maintaining NASTRAN implies a coordination of technical needs between NASA centers. For the maintenance contractor like the MacNeal Schwendler Corporation, to maintain NASTRAN meant to build more rigid formats. To build more rigid formats meant to strengthen the function of NASTRAN. However, maintaining NASTRAN implies another thing. Error correction was another major activity of maintaining NASTRAN. In this aspect, the scarcity of NASA Headquarters' resources still constrained the maintenance of an error correction for NASTRAN. This is to say, to focus on error correction was in favor of aerospace users. To focus on the development of element prototypes was, on the other hand, in favor of automotive users—a new comer in the user community of NASTRAN.

NASA began to coordinate error corrections of NASTRAN when J. Philip Raney directed the NASTRAN office from 1970 to 1973. Raney proclaimed in the first NASTRAN users' colloquium that the central activity for maintenance was error corrections. He further emphasized:

> By faithfully reporting known and suspected errors, each member of the NASTRAN family of users benefits both himself and potentially many others.[59]

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[59] J. Philip Raney, Deene J. Weidman, and Howard M. Adelman, " NASTRAN: Status, Maintenance, and Future Development of New Capability," in *NASTRAN: Users' Experiences*, NASA TM X-2378 Volume II, Washington, D. C., September 1971, pp. 1-7.

Error correction was a good example of NASA's coordination between Centers. The following paragraphs demonstrate this coordination by a negotiation over error corrections. This example is significant because the winning side of the controversy over the adaptation of rigid formats or element prototypes, namely, aerospace users, required both implementing rigid formats and reducing errors to reach their success.

Automotive users, on the other hand, demand another aspect of NASTRAN — element prototypes. Nevertheless, the NASTRAN office did not have all three types of computing machines in which NASTRAN could be used. Other Centers had computers that Langley did not have. For example, the Goddard Space Flight Center (GSFC) had several IBMs. At first, the NASTRAN office and the maintenance contractor sent a team of engineers back and forth to GSFC. On December 3, 1973, the NASTRAN office stated that the use of GSFC's computers through telephone cables would save a considerable amount of time and money now spent in the travel to GSFC. If GSFC would allow the NASTRAN office to access its IBMs through telephone cables. The NASTRAN office could therefore solve IBM-related NASTRAN problems in a much shorter time.[60] Nevertheless, this proposal encountered some resistance. GSFC appealed to NASA Headquarters and provided four reasons against the use of GSFC's computers. First, the computer settings between GSFC's use and NASTRAN's use were different. Hence, GSFC felt difficult to arrange and switch the use of NASTRAN. Second, GSFC feared that GSFC would have to reschedule NASTRAN's use because of a critical need of GSFC. This could create friction and management problems. Third, the uncertainty of GSFC's future use of computers could prevent a critical timing for NASTRAN users. Fourth, the risks associated with loss of GSFC's software to reconfigure the machine for NASTRAN operation are too great to be worth the potential savings to NASTRAN.[61]

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[60] CP, p. 1.

[61] CP, p. 6.

NASA Headquarters coordinated this negotiation between the NASTRAN office and the Goddard Computing office. NASA Headquarters approved the NASTRAN office's request and assuaged GSFC in this way:

> Goddard would also benefit from the cooperative effort. GSFC's NASTRAN users would not be able to get much quicker service on error corrections, and NSMO [the NASTRAN office] could make available the most recent version of utility routines for the IBM version of NASTRAN. The NASTRAN users at Goddard would also have access to the most up-to-date levels of NASTRAN.[62]

As a result, NASA Headquarters prioritized the coordination of NASTRAN users to GSFC's computing and organizational requirements. This result also suggested that NASA attempted to maintain NASTRAN across different Centers and to maximize the benefit of using NASTRAN. This effort to channel the technical communication of NASTRAN, from NASA's point of view, would significantly increase productivity.

NASA not only coordinated NASTRAN between Centers but also assigned NASTRAN a set of rigid formats to aid NASA's Shuttle mission: flutter capability. At NAG's meeting in 1973, NAG proposed to negotiate with aerospace users which program should include which technical specialty. This division of labor strongly influenced the fate of NASTRAN. The report of NAG's meeting stated:

> First of all it should be noted that ATLAS is only a Class II program. If Boeing, who is providing ATLAS to Langley, objects sufficiently to the contract terms, it could conceivably end up as a Class I program. Langley is purchasing ATLAS to use as a design program for the AST and it must have complete flutter capability to be useful. It was also stated, but not confirmed, that there was no strong need for complete flutter capability in a Class III program. It was assumed the companies

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[62] CP, p. 8.

> already had the capability, although not associated with a NASA Class III program.[63]

In this memo, NASTRAN was compared with other aerospace computing programs, such as ATLAS or FLEXSTAB (see the next quote). The negotiation focused on which program should include "flutter-analyzing capability", and which program should be classfied into class I, II or III in terms of their use. The report continued to state that the course of action was subject to further negotiation between NASA Centers and aerospace users. The flutter-analyzing capability concentrated on whether the Shuttle would be strong enough to experience flutter. The significance of this negotiation was that the flutter-analyzing capability could help to analyze and judge if the structure of Shuttle could go through both the subsonic and supersonic zone. Hence, which "aero-elastic" capability to be assigned and maintained would partially result from NASA's negotiation with aerospace contractors over the flutter problems.

Langley used NASTRAN as an analytical tool and Ames Research Center used FLEXSTAB. They both needed an exchangeable format to solve flutter problems. The report claimed:

> It was recommended not to start the NASTRAN effort and include the capability in FLEXSTAB only. It is assumed that FLEXSTAB will be a fully operational Class III program with full maintenance and distribution. Ames is requested to submit a complete plan describing the future plans for FLEXSTAB development, including an executive and modularization of capability. It should also interface with NASTRAN so that the two programs can be used together with a minimum of modification. It should also indicate the computers on which it will be planned to run. Funding requirements should also be listed along with the planned sources of funding.[64]

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[63] Memorandum, p. 2.

[64] Memorandum, p. 2.

This coordination between Langley and Ames resulted from NASA Headquarters' overall plan for the Shuttle project. NASA's hierarchy emphasized NASTRAN and FLEXSTAB to the near-term effects on improvements as airframe-problem-solving tools, especially flutter problems. More importantly, NASA argued that these two programs should be able to exchange technical information. No matter which was to include flutter capability, NASTRAN and FLEXSTAB could both share the same analytical outcomes.

The result of all these negotiations, immediately following the declaration of the Shuttle project by President Nixon in 1973, was to put NASTRAN into the busy schedule of the Shuttle project.[65] NASA concentrated the maintenance on rigid formats and functional modules to solve flutter problems. The report described the schedule of the Shuttle requirements for aero-elastic capability at Johnson Space Center. NASA Headquarters decided the following course of actions:

> 1. Subsonic flutter capability by October 1973 in order to be operational at JSC prior to Shuttle Preliminary Design Review in early 1974.
> 2. Supersonic flutter capability during the first quarter of 1975 in order to be operational at JSC prior to Contractor Design Review (Structures) in mid 1975.[66]

For NASA's purposes, NASTRAN was not needed as a design tool, just as an analysis to check the design. It was also necessary, from NASA's point of view, that the flutter capability be included in NASTRAN because NASA divided its computing labor into various tasks and NASTRAN should take care of flutter problems. In summary, Aerospace users won the controversy over maintaining NASTRAN by successfully elaborating with NASA, implementing many rigid formats into NASTRAN, and thus controlling the process of error correction. On the

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[65] Gillette, Robert, "Space Shuttle: Compromise Version Still Faces Opposition," in *Science* 175 [January 28, 1972], pp. 381-390.

[66] Memorandum, p. 1.

other hand, automotive engineers proposed to implement more element prototypes but did not gain NASA's recognition.

In response to the requests of aerospace users, NASA's NASTRAN office organized its maintenance activities into different groups according to the computing machines used by aerospace engineers. The June 14, 1974, NASTRAN Newsletter[67] announced a proposal to form mutual interest groups for NASTRAN users with IBM Virtual Storage computers and the CDC 6600 computers running SCOPE 3.4 Operating system. The purpose of these groups, according to the NASTRAN office, was to "have open communication among all members to alleviate some of the problems encountered when running NASTRAN on an IBM OS/VS computer [or CDC SCOPE 3.4 Operating system]."[68] The NASTRAN office attempted to "keep all group members up to date on any new NASTRAN modifications that [would] be beneficial to them."[69] Although the NASTRAN office did not have access to IBM or CDC computers, NASA conducted "a study that [had] been funded in that area."[70] The Shuttle project financially supported this study; and the NASTRAN office sent the results of this study to aerospace users.

These "mutual interest groups" contained mostly aerospace users except the maintenance contractor, MacNeal Schwendler Corporation. The group with an IBM Virtual Storage Computer included Grumann, Beech Aircraft, British Aircraft, Atomic Weapon Research Establishment in DOD, Bell Helicopter, Teledyne CAE, Rockwell International, Boeing, MacNeal-Schwendler and Pratt & Whitney Aircraft. The group with a CDC SCOPE 3.4 Operating System included Frankford Arsenal, Sandia Lab, General Dynamics, Sperry Rand, Reactor Centrum Nederland,

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[67] I have obtained a complete collection of NASTRAN Newsletters from Joseph Walz. I appreciate his generous help in providing all these documents. Mr. Walz worked in the NASTRAN office since the early 1970s.

[68] CP, p. 64.

[69] CP, p. 65.

[70] CP, p. 65.

and MacNeal Schwendler.[71] These mutual interest groups set up the communication link between aerospace users in social terms, which is both significant and important for them.

NASA also mentioned and emphasized this communication link in technical terms. In the eyes of aerospace engineers, applications of NASTRAN became increasingly significant in reducing the cost of computations because of the implementation of rigid formats. As NASA's chief in the Dissemination and Program Evaluation, Technology Utilization Office, Joseph M. Carlson, advocated:

> The most significant direct economic benefits to NASTRAN users are attributed to substantial increases in productivity, which have enabled significant reductions in real operating costs. Four primary factors, listed as effecting the increases, are 1) analyses have been accomplished which could not have been done without NASTRAN; 2) more complete and accurate results have been obtained; 3) development time has been shortened; and, 4) *communications* between engineers and programmers have been improved because of the standardization of technology and mathematical approaches developed in NASTRAN. (emphasis mine)[72]

The most important benefit for NASA was in communication. Aerospace engineers working on the same mission and doing analysis with the same program could feed data between each other in such cases when one analysis required information supplied from several sources. This process also required unified and specific modeling techniques — rigid formats. The benefits in technical communication of NASTRAN became extraordinarily productive for NASA to handle the Shuttle project in the post-Apollo years. The technical communication of NASTRAN fit NASA's coordination and specialization in its hierarchical organization. To exchange and coordinate both

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[71] CP, p. 66.

[72] Joseph M. Carlson and Judson O. Harrison III, "NASTRAN: A Preliminary Discussion of User Impacts," in *Journal of Aircraft*, Vol. 10, No. 2, February 1973, p. 65.

the technical and organization information based on the unification of both organizational and technical structure and functions. The rigid formats played an important role.

NASA's maintenance of NASTRAN steered the automobile industry away from the selected user community by only maintaining the aerospace functions and modules of NASTRAN. Automotive engineers wanted another technical orientation that NASA did not thoroughly supply. They wanted more "element prototypes" in NASTRAN. The matrix approach embedded in NASTRAN requires different assumptions of basic elements to begin its analysis. For example, the simplest element for the matrix analysis is the bar element. Engineers presumed an idealized bar that could only bear tension or compression. Hence, this element could be described by a set of mechanical characteristics. For each element, aerospace engineers could formulate a small set of equations to describe it. Then aerospace engineers "assembled" these small elements into the actual airframe they want to analyze. This is to say, they integrated many small sets of equations into one large set of algebraic equations. While analyzing each element, NASTRAN provided a library of elements for aerospace engineers to choose from. The library had basic elements such as bar, rod, tube, panel, membrane, plate, and shell.[73] Automotive engineers demanded more elements to model configurations of automobiles than NASTRAN could provide.

NASA's strategic selection of "aerospace" rather than "aotumotive" module configurations (rigid formats) can be illustrated by the following example. Knut S. Skattum, a research engineer in the General Motors Corporation, submitted a paper to the NASTRAN Users' Colloquium to demonstrate a modeling technique for automotive frames. This modeling technique was to modify "the composite element" provided by NASTRAN's library of elements. His purpose was

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[73] Thomas G. Butler and Douglas Michel, *NASTRAN: A summary of the Functions and Capability of the NASA Structural Analysis Computer System*, 1971, Scientific And Technical Information Office, NASA, Washington D.C., pp. 9-10.

to model thin walls of automotive frames containing some holes. This modeling required new elements from NASTRAN to accomplish the accuracy of analysis. Skattum stated in his conclusion in this way:

> It is hoped that future editions of NASTRAN can present a true thin-walled beam since the need for proper modeling will increase. Until that time, the present composite element is available, it is accurate, and easy to use.[74]

The element library of NASTRAN only provided the basic elements for modeling aerospace problems. To develop new elements required significant amount of work and money. Skattum as a research engineer participated in the NASTRAN Users' Colloquium held by aerospace users' community and attempted to address this issue for automotive engineers. Skattum's attempt indicated that automotive engineers could not express their needs of NASTRAN. Moreover, his voice did not seem loud enough to be heard in an aerospace conference. SAE therefore recognized that to participate in the NAG meeting would provide them with some strength expressing their needs.

The Computer Application Committee in SAE mediated the contact between NASA and the automotive engineers to express the need of automotive engineers. Dr. Joseph Wolf of the General Motors Corporation, a member of SAE, presented the automotive engineers' views about NASTRAN to NASA. Wolf pointed out that there were approximately 300 users of NASTRAN in automobile companies, with about 90 within General Motors. He expressed enthusiasm about the program and the hope that NASA would continue to maintain and improve it.[75]

The automobile companies then attempted to participate in the NASTRAN Advisory Group. Lajos T. Nagy, Vice-chairman of the Society of Automotive Engineers (SAE) Computer

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[74] Knut S. Skattum, "Modeling Techniques of Thin-Walled Beams with Open Cross Sections," in *NASTRAN Users' Experiences*, NASA TMX-2637, Washington D.C., September 1972, pp. 179-195.

[75] Memorandum, p. 2.

Application Committee, wrote a letter to NASA's Langley Research Center on January 9, 1975 and asked for participation:

> We, as representatives of the SAE Computer Application Committee, feel that establishing a communication link between NSMO [the NASTRAN office] and the NASTRAN users is essential. Although we tried in the past, as the attached letter indicates, we have had no response. Therefore, we are seeking your advice in the matter of obtaining representation.[76]

Nagy's letter indicated that SAE had tried several times. The "communication link" expressed automotive engineers' wish to alter some configuration of NASTRAN. To obtain representation in NAG would position SAE to enunciate their needs. Hence, SAE tried hard to push this line.

However, the automotive engineers could not participate in NAG. R. W. Leonard, the Associate Chief of the Structure and Dynamics Division at Langley and a member in the NASTRAN Advisory Group[77], replied to Nagy's letter on February 13, 1975 and refused his request. Leonard explained:

> I must, however, advise that NASA's ability to satisfy special maintenance and improvement needs of non-aerospace users is very low. The NASA's budgets and manpower ceilings have steadily shrunk since NASTRAN was first released and the demands for services from the rapidly growing user community now exceed our available resources by a wide margin. In keeping with NASA's statutory responsibilities, we must give priority to the needs of NASA Centers, the aerospace industry and the DOD.[78]

However, SAE did not abandon this effort easily. It also attempted to ally more automotive engineers to demonstrate their broader needs. Nagy continued to write:

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[76] CP, p. 56.

[77] Memorandum, p. 8.

[78] CP, pp. 60-73.

> I have talked to finite element experts at General Motors, Ford, Chrysler, Westinghouse, and other non-aerospace companies. They are all in agreement with me that NASA should include some of us in the NASTRAN Advisory Committee to represent our needs and requirements.[79]

This continuing effort to obtain representation in NAG touched the ambivalent performance of NASA's hierarchy and its public work. Although NASA's roles were ambivalent, NASA still had to make important choice in the course of action.

The automotive engineers' "special needs" did not concern NASA. In Leonard's explanation, NASA could not afford investing extra effort and money because "NASA's budgets and manpower ceilings [had] steadily shrunk." On the contrary, NASA's "statutory responsibilities" should be NASA's top priority. NASA's rhetoric did not seem convincing to automotive engineers because they attempted to mobile more automotive users. In any event, NASA gradually moved NASTRAN toward a specialized niche to analyze flutter problems in the Shuttle mission. The technological choice also locked on its organizational one. NASA's decision at work bears blueprints of both social and technical dimensions at the same time.

In short, the principal story line of chapters two and three goes as follows: NASA had a crisis of legitimacy after the Apollo mission. Headquarters became more and more involved in coordinating. It also sought sources of legitimacy by trying to serve new constituencies, such as automotive users. Headquarters justified NASTRAN as a way of coordinating aerospace work at three different centers and reaching out to new industries. Things changed after NASTRAN had been developed. Just maintaining thorough error correction became a costly activity and each center had its own issues. Also, the approval of shuttle project provided a focus for NASA as a space agency again, with Headquarters still coordinating more than previously. Headquarters no

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[79] CP, p. 74.

longer needed other industries, in this case the automobile industry, and sanctioned technical moves in the code that consolidated aerospace interests around the shuttle project.

Chapter 4

Conclusion

After the Apollo mission, as Feynman has suggested, NASA did not "want to fire people and send them out in the street" after NASA had finished its "big project."[80] Therefore, on the one hand, NASA had to "convince Congress that there exists a project that only NASA can do," and, on the other hand, NASA wanted to be perceived as a public government agency that benefits "the general public." In the story of NASA and NASTRAN, I have argued that the post-Apollo NASA fell into a crisis of political legitimacy. NASA Headquarters became more and more involved in coordinating different space centers and intended to sell another project to Congress, and also sought for new sources of legitimacy by trying to serve new constituencies. These new sources of legitimacy included many technological spin-offs in public affairs and automotive users as one of those new constituencies.

In such a crisis of political legitimacy, one of those chief protagonist from NASA Goddard Space Flight Center, Thomas Butler, observed, when he was sitting in NAG (NASTRAN Advisory Group) directed by NASA Headquarters, that the maintenance of NASTRAN required “the spirit of partnership between government and industry that pertained in the old NACA days.” He went on to quote Richard Martin of Convair / San Diego:

> At first, I was opposed to government incursion into the industry province of analysis program development. The longer I reflected, however, the more I began to realize that there is a *proper role for government* here. The quantity of analytical routines that have achieved competence is so great today compared to several years ago that the costs of developing these big, general purpose finite element programs

[80] Richard P. Feynman, *"What Do You Care What Other People Think?" Further Adventures of a Curious Character* , W W Norton & Company, 1988, pp. 213 - 215.

> are so great that individual companies can no longer afford to write their own programs. I think it is a proper role for government to shoulder the cost and responsibility for our modern finite element programs and serve all industry with such up-to-date analytical tools. It doesn't make sense any more for everyone to go his own separate way. I personally endorse what you are doing in the NASTRAN project.[81]

When NASA emerged in the late 1950s, aerospace industries held the idea that NASA should only coordinate the efforts of aerospace computing, instead of "shouldering the cost and responsibility" of them. Martin, however, advocated a "proper role" for NASA in intervening or even directing the computing tasks of aerospace industries. Martin supported NASA's promotion of its space technology. His "proper role" of government represents only the interests of aerospace users and serves to justify NASA Headquarters' coordination and intervention.

I hold a different view from Martin's. In this thesis, I intend to show that the social and the technical come together in a historical event *by chance.* I want to demonstrate the contingency in the development and maintenance of NASTRAN computer program. No critique is complete until the two, namely, the social and the technical, have been shown to arise from a single cause by its very contingency. This is what I have learned from the critical studies of technology discussed in chapter one. However, I also learned from humanist studies of technology that we should not ignore the contingency of different human actors' efforts in mobilizing resources while trying to achieve their goals. I will reflect on the NASA and NASTRAN story in light of these two approaches and attempt to understand the overlapping areas as pointedly as possible.

First, both humanist studies and critical studies of technology emphasize the conjuncture between the "technical contents" and their "social uses." In chapter one, I have detailed how aerospace engineers centered their concerns on developing a specific method to exploit computing machines, mathematical tricks, and organizational resources. This specific method was the matrix approach, the basis of NASTRAN computer program. The genesis of NASTRAN computer

[81] T. G. Butler, "On the Reduction of Proliferation of Finite Element Programs," in *NASTRAN Users' Experiences*, NASA TM X-2378 Volume II, D.C., September 1971, p. 821. Emphasis added.

program underwent several conjunctures of both the technical and the social. The social use of technical knowledge largely shapes the fate of that particular technology. For example, the "structural elements" in the NASTRAN computer program were crucial for the aerospace analysis and design at the beginning and later became central to automotive users. The subroutines (or rigid formats) in the matrix approach were marginal when the Apollo mission faded out but became significant when the Space shuttle project came along. On the other hand, actors cannot reshape technologies in whatever ways they want. The negotiation between the NASTRAN office and aerospace and automotive users, as well as the intervention of NASA Headquarters demonstrates how the technical contents conditioned the mobilizing efforts of actors. For example, NASA's decision to freeze out the automotive industries was conditioned by the technical contents of NASTRAN computer program. I want to show that even such a powerful agency as NASA cannot dominate the entire process of negotiation by freezing the automotive users, socially as well as technically.

Second, the technical contents of NASTRAN and the ideological elements of NASA become my central concern because of their unique communication and coordination. The interdependent disciplines of analytical mechanics, numerical methods, and computer program make the technical contents of NASTRAN possible. The story of the NASTRAN project shows the interlocking process of this interdisciplinary knowledge and its organizational use. However, I also intend to demonstrate an ideological dimension in NASA's use of NASTRAN. This notion of ideology needs some clarification. I think ideology is he central problem of the studies of science and technology because the studies of science and technology has to do with meaning and knowledge, its production, distribution, and consumption in various historical and social settings. This is why I call for further investigation in the production of this ideological dimension within the story of NASA and NASTRAN. After the Apollo mission, NASA withdrew by dragging NASTRAN away from those aerospace and automotive users. NASA performed in a contradictory way precisely because (1) NASA presented itself, like other government agencies, as a public benefactor in the free market, and (2) NASA could not fully justify this position as a public benefactor. NASA's strategic allocation and use of NASTRAN illustrates the contingency of the development and maintenance of NASTRAN in its political contexts.

Well, is it enough to show the radical historical contingency and modes of construction for everything? Haraway provides a suggestion in her celebrated essay, "Situated Knowledge," in this way:

> I think my problem and "our" problem is how to have simultaneously an account of radical historical contingency for all knowledge claims and knowing subjects, a critical practice for recognizing our own "semiotic technologies" for making meanings, and a no-nonsense commitment to faithful accounts of a "real" world, one that can be partially shared and friendly to earth-wide projects of finite freedom, adequate material abundance, modest meaning in suffering, and limited happiness.[82]

This vision is inspiring to me. As an interpreter and actor, I decide to find out more about this "no-nonsense commitment" to faithful accounts of reality. I believe that, in this vision, we may find a hope of our practices and also a resolution of our theoretical dilemma about the notion of agency.

This body of literature on "technoscience studies" goes through several lines of inquiries that challenge not only the notion of agency and contingency, but also our radically changing vision of truth, logic, reason, meaning, knowledge and reality. Haraway's "no-nonsense commitment" implies a vision of politics that explore all kinds of linguistic possibilities for knowledge and meaningful statements. This vision emphasizes sharing, possible worlds, and accountability. She suggests that "politics rests on the possibility of a shared world. Politics rests on the possibility of being accountable to each other, in some non voluntaristic 'I feel like it today' way." Our cultural discourse, constantly refreshed by new metaphors (a problem of being in the belly of monster and looking for another story to tell), should be the expression of our common concerns about "any object of knowledge and related claims about the faithfulness of our accounts

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[82] Haraway, Dona J., "Situated Knowledge: The Science Question in Feminism and the Privilege of Partial Perspective," in *Simians, Cyborgs, and Women: The Reinvention of Nature*, Routlege, New York, 1991, p. 187.

of a 'real world,' no matter how mediated for us and no matter how complex and contradictory these worlds may be." Further, this should be coupled with a critical practice of semiotic technologies. Having elaborated with Latour's actor-network theory, Haraway suggests that we doubt that "an object of knowledge is a passive and inert thing." On the contrary, she contends that:

> Situated knowledges require that the object of knowledge be pictured as an actor or agent, not a screen or a ground or a resource, never finally as slave to the master that closes off the dialectic in his unique agency and authorship of 'object' of knowledge. The point is paradigmatically clear in critical approaches to the social and human sciences, where the agency of people studied itself transforms the entire project of producing social theory.[83]

This proposal is critical, provocative, and interesting. I provide this vision for us to reflect upon at the end of our story of NASA and NASTRAN.

NASA, NASTRAN and aerospace users together formed a high-tech community. Herbert Marcuse has described that such a domination of the high-tech community is substantive and belongs to very form of technical reason. Langdon Winner and Donald MacKenzie paid careful attention to how technological community functions in our society. This thesis borrows insights from both Winner and MacKenzie and it attempts to synthesize some of their theoretical strategies, such as sociotechnical parallel, negotiation between actors, and abstinence from either social or technological determinism. By recounting the case of NASA and NASTRAN, I have attempted to bring the dimensions of technology into the radical-critical tradition. The moral-analytic message could be paraphrased in Marcuse's diagnosis thirty years ago:

> Today, domination perpetuates and extends itself not only through technology but *as* technology, and the latter provides the great legitimation of political power, which absorbs all spheres of culture.

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[83] Ibid. p. 198.

> In this universe, technology also provides the great rationalization of the unfreedom of man and demonstrates the "technical" possibility of being autonomous, of determining one's own life. For this unfreedom appears neither as irrational nor as political, but rather as submission to the technical apparatus which enlarges the comforts of life and increases the productivity of labor. Technological rationality thus protects rather than cancels the legitimacy of domination and the instrumentalist horizon of reason opens on a rationally totalitarian society.[84]

Marcuse took a very pessimistic position in the radical-critical tradition. The story of NASA and NASTRAN occurred at the time when he was witnessing a "rationally totalitarian society."

In the story of NASA and NASTRAN, I wish to show that Marcuse's pessimism needs not be as strong as it was before. It can be revised and perhaps substituted by Haraway's vision. There are many crossroads taken by different actors. However, we should not underestimate the sources of Marcuse's pessimism. This thesis wants to provide that detail that shows how technology works in a certain way. In theoretical discussion, we have encountered critical physicist like Feynman, philosophers like Winner, social historian like MacKenzie, critical theorist like Marcuse, and a new vision provided by Haraway. Together these works provide a new baseline form which further discussion on "rethinking technologies" should begin. I hope my story of NASA and NASTRAN is a good attempt.

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[84] Habermas, Jürgen, *Toward a Rational Society: Student Protest, Science and Politics*, translated by Jeremy J. Shapiro, Beacon Press, Boston, pp. 84-85.

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