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AFRPL Technical Objective Document

FY87

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Air Force Rocket Propulsion Laboratory

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DON A. HART
Director, Air Force Rocket Propulsion Laboratory

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This report is a summary of technical objectives and approaches for research, exploratory development, and advanced development efforts being pursued, and to be pursued, at the Air Force Rocket Propulsion Laboratory between FY 86-91.

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AFRPL TECHNICAL OBJECTIVE DOCUMENT

FY 87

TABLE OF CONTENTS

INTRODUCTION

The Air Force Technical Objective Document (TOD) program is an integral part of the process by which the Air Force plans and formulates a detailed technology program to support the development and acquisition of Air Force weapon systems. Each Air Force laboratory annually formulates a Research and Technology (R&T) Plan in response to available guidance based on USAF requirements, the identification of scientific and technological opportunities, and the needs of present and projected systems. These plans include proposed efforts to achieve desired capabilities, to resolve known technical problems, and to capitalize on new technical opportunities. The proposed efforts undergo a lengthy program formulation and review process. Generally, the criteria applied during the formulation and review are responsiveness to stated objectives and known requirements, scientific content and merit, program balance, developmental and life cycle costs, and consideration of payoff versus risk.

It is fully recognized that the development and accomplishment of the Air Force technical program is a product of the teamwork on the part of the Air Force laboratories and the industrial and academic research and development community. The TOD program is designed to provide to industry and the academic community, necessary information on the Air Force laboratories' planned technology programs. Each laboratory's TOD is extracted from its R&T planning activity.

Specific objectives are:

a. To provide planning information for independent research and development programs.

b. To improve the quality of the unsolicited proposals and R&D procurements.

c. To encourage face-to-face discussions between non-Government scientists and engineers and their Air Force counterparts.

One or more TODs have been prepared by each Air Force laboratory that has responsibility for a portion of the Air Force Technical Programs. Classified TODs are available from the Defense Technical Information Center (DTIC) and unclassified/unlimited TODs are available from the National Technical Information Service (NTIS).

The AFRPL TOD contains a general overview of the Laboratory and its planned program. The appendix contains a program listing of our FY-86 and 87 expected new competitive contracted programs. These program listings are extracts from preliminary internal planning documents and should be viewed in that light. It is also important to remember that at the time this program list was prepared, it is like a "snapshot-in-time" and is subject to change.

HOW TO USE THIS DOCUMENT

Unsolicited proposals to conduct programs leading to the attainment of any of the objectives presented in this document may be submitted directly to an Air Force laboratory. However, before submitting a formal proposal, we encourage you to discuss your approach with the laboratory point of contact. After your discussion or correspondence with the laboratory personnel, you will be better prepared to write your proposal.

As stated in the "AFSC Guide for Unsolicited Proposals" (copies of this informative guide on unsolicited proposals are available by writing to Air Force Systems Command/PMPR, Andrews Air Force Base, Washington, DC 20334), elaborate brochures or presentations are definitely not desired. The "ABCs" of successful proposals are accuracy, brevity, and clarity. It is extremely important that your letter be prepared to encourage its reading, to facilitate its understanding, and to impart an appreciation of the ideas you desire to convey. Specifically, your letter should include the following:

1. Name and address of your organization.

2. Type of organization (profit, non-profit).

3. Concise title and abstract of the proposed research and the statement indicating that the submission is an unsolicited proposal.

4. An outline and discussion of the purpose of the research, the method of attack upon the problem, and the nature of the expected results.

5. Name and research experience of the principal investigator.

6. A suggestion as to the proposed starting and completion dates.

7. An outline of the proposed budget, including information on equipment, facility, and personnel requirements.

8. Names of any other Federal agencies receiving the proposal (this is extremely important).

9. Brief description of your facilities, particularly those which would be used in your proposed research effort.

10. Brief outline of your previous work and experience in the field.

11. If available, you should include a description brochure and a financial statement.

As you read through the pages that follow, you may see a field of endeavor where your organization can contribute to the achievement of a specific technical goal. If such is the case, you are invited to discuss the objective further with the scientist or engineer identified with that objective. Further, you may have completely new ideas not considered in this document which, if brought to the attention of the proper organization, can make a significant contribution to our military technology. We will always maintain an open mind in evaluating any new concepts which, when successfully pursued, would improve our future operational capability.

On behalf of the United States Air Force, you are invited to study the objectives listed in this document and to discuss them with the responsible Air Force personnel. Your ideas and proposals, whether in response to the TODs or not, are most welcome.

The Air Force Rocket Propulsion Laboratory's technology program is organized into applications oriented major thrusts: one for each of the three major rocket propulsion applications areas, i.e., space systems, ballistic missiles, and air-launched missiles. Two other major thrusts make up the remainder of the Laboratory's program: one for technology which is (or will be) applied to several application areas, and one for, generally, non-propulsive space technologies which can best be described as Interdisciplinary Space Technology. The points of contact for these major thrust areas, should you desire additional information, are:

Space Systems Propulsion Technology Interdisciplinary Space Technology	1Lt Eric DiStefano AFRPL/XRX Autovon 350-5344 Commercial (805) 277-5344
Ballistic Missile Propulsion Technology	1Lt Jann Cassady AFRPL/XRX Autovon 350-5346 Commercial (805) 277-5346
Air-Launched Missile Propulsion Technology	Mr Robert Biggers AFRPL/XRX Autovon 350-5341 Commercial (805) 277-5341
Multiple Applications Rocket Prop Tech	Mr Wayne Roe AFRPL/XRX Autovon 350-5206 Commercial (805) 277-5206
Strategic Defense Initiative Propulsion Technology	Dr Richard Weiss AFRPL/CR Autovon 350-5622 Commercial (805) 277-5622

LABORATORY MISSION

The Air Force Rocket Propulsion Laboratory (AFRPL) is the principal AFSC organization charged with planning, formulating and executing the USAF technology programs for rocket propulsion and related interdisciplinary space technology. There are two parts to the AFRPL mission - first to develop new technology for the Air Force missiles and space systems of the future; and second to provide technical support to other organizations within the Air Force, particularly the Systems Program Offices (SPOs) that produce end items. This mission is graphically depicted in Figure 1.

The technology advancement programs cover the complete spectrum of detailed basic research (6.1), exploratory development (6.2) and advanced development (6.3). The Laboratory is responsible for maintaining a superior technical base in all types of rocket propulsion and related disciplines, as listed inside the arrow on Figure 1, which will provide options for the development of future high performance Air Force systems and to prevent technological surprise. The technical support, or technological assistance includes: engineering and scientific consultation, technical direction of programs, managing contractual efforts and executing in-house analytical and experimental programs.

INVESTMENT STRATEGY

The Laboratory strives to have a balanced investment strategy that takes into account (1) Air Force needs as stated by the system users, (2) Air Force mission capability deficiencies as identified in documents such as Vanguard Planning Summary, Military Space Systems Technology Plan (MSSTP), and the Logistics Long Range Planning Guide, and (3) basic technological advances, otherwise known as "Technology Push." We use an in-house management council, made up of the Director and eight senior Laboratory members, to make the decisions on where we will make an investment. Decisions are made within the limitations of the Laboratory's budget, manpower and facilities. Our planning process is shown in Figure 2. We take into account the "Big Picture" at the start of the process, assessing the Air Force needs for each of our major thrust areas. Resource allocations are issued for each of our technology clusters. We go through a process of internal competition at the cluster level evaluating ideas for new programs and also evaluating the on-going cluster levels of investment. We always demand of ourselves whether we have a valid rationale that answers, "what's in it for the Air Force?" We consider whether the program is answering a valid Air Force requirement or whether it is a fundamental effort that will exploit technology to achieve increased or new capabilities. We realize that there are times when we should strive to extend technological boundaries, and we do invest in these areas, but we also don't do technology for technology's sake - we do it for the Air Force's sake. We do it because we believe that with this new technology it will find application in Air Force Systems of the future and, therefore, it is a good investment.

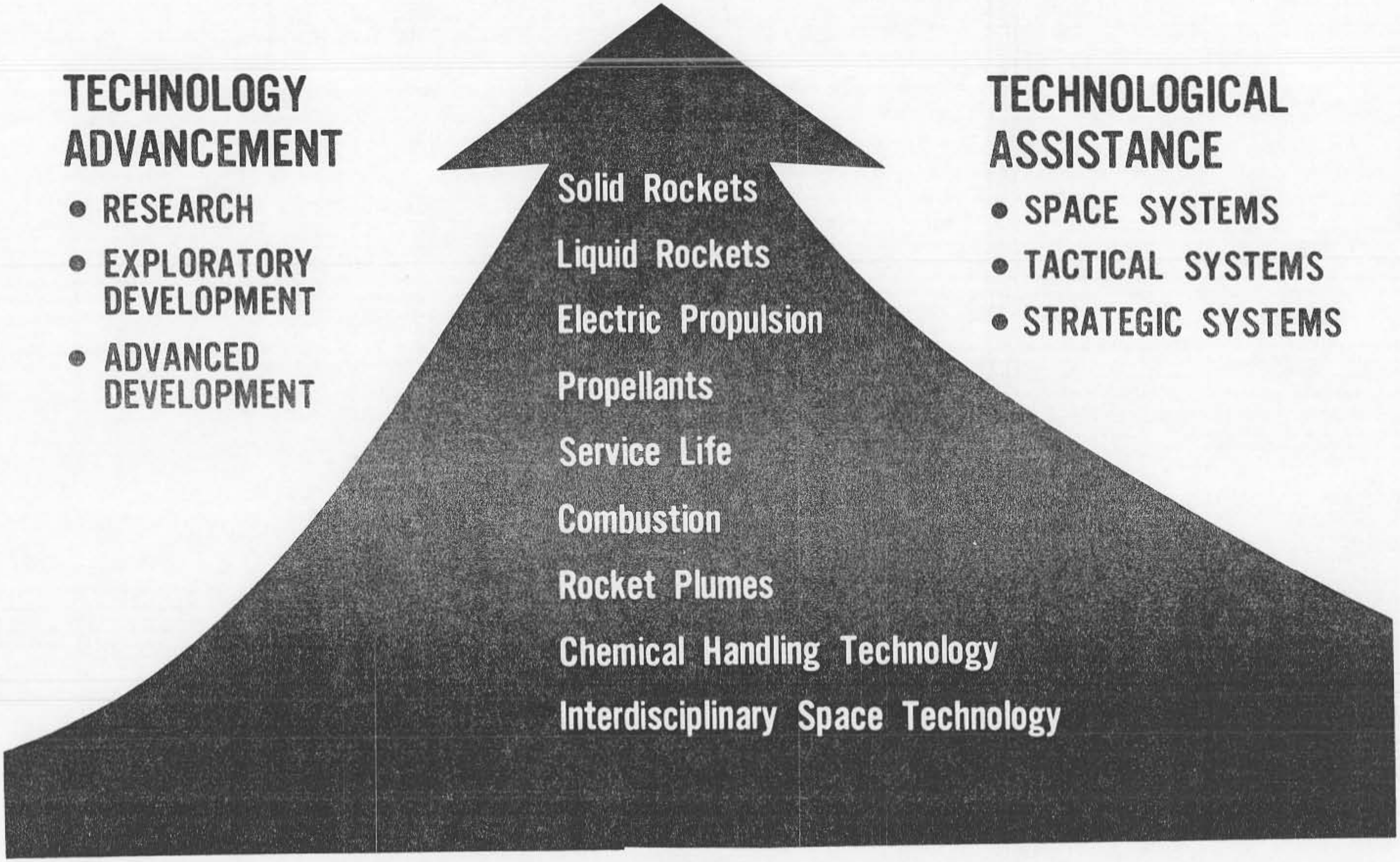
The Air Force Rocket Propulsion Laboratory's program is organized into five Technical Thrusts: One for each of the three major rocket propulsion applications areas, i.e.,; ballistic missiles, air-launched missiles and space propulsion systems; one for propulsion technology which is (or will be) applied to several application areas; and one for non-propulsive space systems. The AFRPL/AFOSR Basic Research (Program Element 61102F) program summary description is shown in Figure 3. The five Technical Thrusts are congruent with the five projects under the Laboratory's Exploratory Development Program Element (62302F). A summary

AFRPL MISSION....

TECHNOLOGY for AIR FORCE SYSTEMS

TECHNOLOGY ADVANCEMENT

- RESEARCH
- EXPLORATORY DEVELOPMENT
- ADVANCED DEVELOPMENT



TECHNOLOGICAL ASSISTANCE

- SPACE SYSTEMS
- TACTICAL SYSTEMS
- STRATEGIC SYSTEMS

FIGURE 1

AFRPL PLANNING PROCESS....

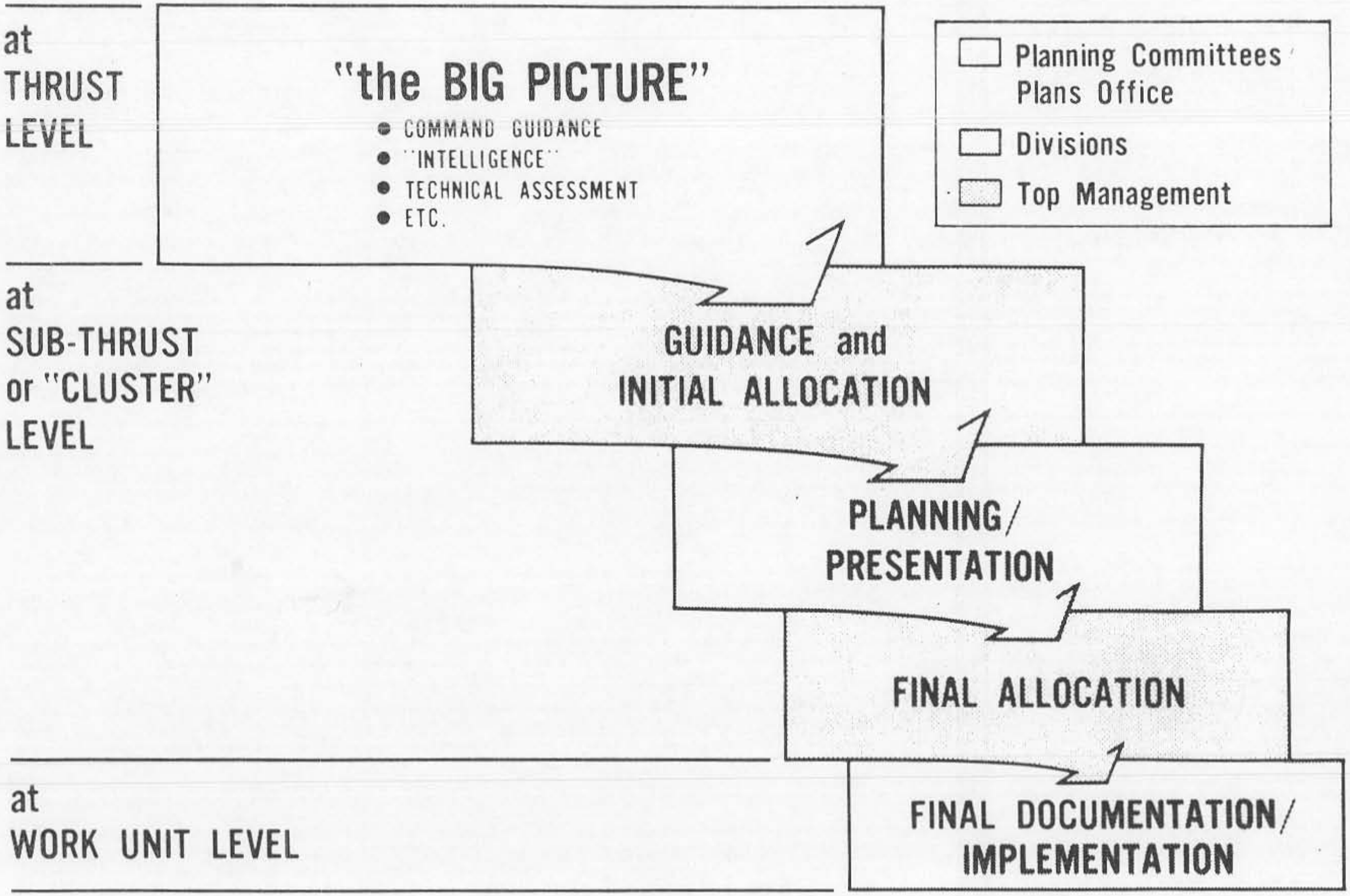


FIGURE 2

AFRPL/AFOSR Basic Research....

OBJECTIVES

- Conduct Research in
  - New Energetic Compound Synthesis
  - C/C Processing Variables
  - Fracture & Aging Behavior
  - Energy Exchange Mechanisms
  - Chemical Kinetic Influences
  - Advanced Concepts

TASKS

- Propellant Ingredient Research
- Rocket Nozzle Recession Kinetics
- Propellant Structural Mechanics
- Combustion
- Plumes
- Nonconventional Propulsion

8

FUNDING ($K)

PE	FY85	FY86	FY87
61102F	1.9	2.0	2.0

PAYOFFS:

- Cleaner Design Alternatives
- Magnitude Gains in Usable Thrust
- New Knowledge for Technologies
- Peer Interactions with Lab S&E
- Transition Research Findings to 6.2 Dev.

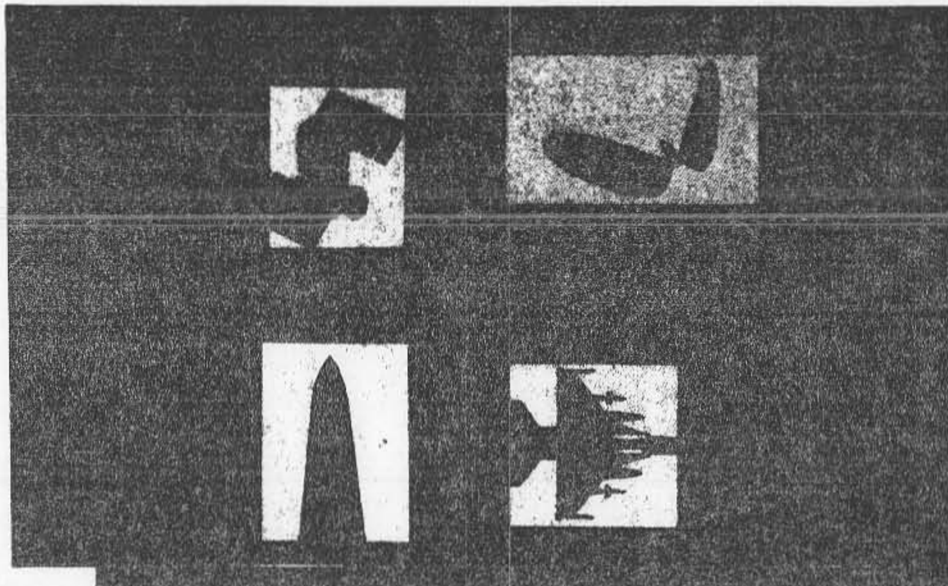
FIGURE 3

of the 6.2 program is shown in Figure 4. Our Space and Missile Rocket Propulsion Advanced Technology Development (63302F) projects are aligned with our three applications oriented Technical Thrusts. A summary of the 6.3 program is shown in Figure 5.

A breakout of the exploratory develoment program to the subthrust, or cluster, level is shown in Figure 6. The area of the boxes is porportional to the amount of 62302F funds allocated for each cluster.

The rocket propulsion technology applicable to the Strategic Defense Initiative (SDI) is accomplished within the present sub-thrust structure of the Laboratory. However, the overall SDI technology development is under the auspices of a separate SDI Technology Office. The focal points, and their respective areas of responsiblity, within the SDI Technology Office are shown in Figure 7.

Rocket Propulsion 62302F....



THRUSTS:

- Space Propulsion
- Interdisciplinary Space Technology
- Air-Launched Missile Propulsion
- Ballistic Missile Propulsion
- Multiple Application Technology

FUNDING ($×Millions):*

FY85	FY86	FY87
34.6	41.7	45.1

*Based on FY87 POM

PAYOFFS:

- A/L Mission Range Increase
- Reduced Observables
- Survivable/Flexible Basing Modes
- Lower Costs/Higher Reliability
- More Payload to GEO
- 40% Increase in Satellite Life
- 75% Reduction in Radiator Weight
- Increase in ASAT Capability

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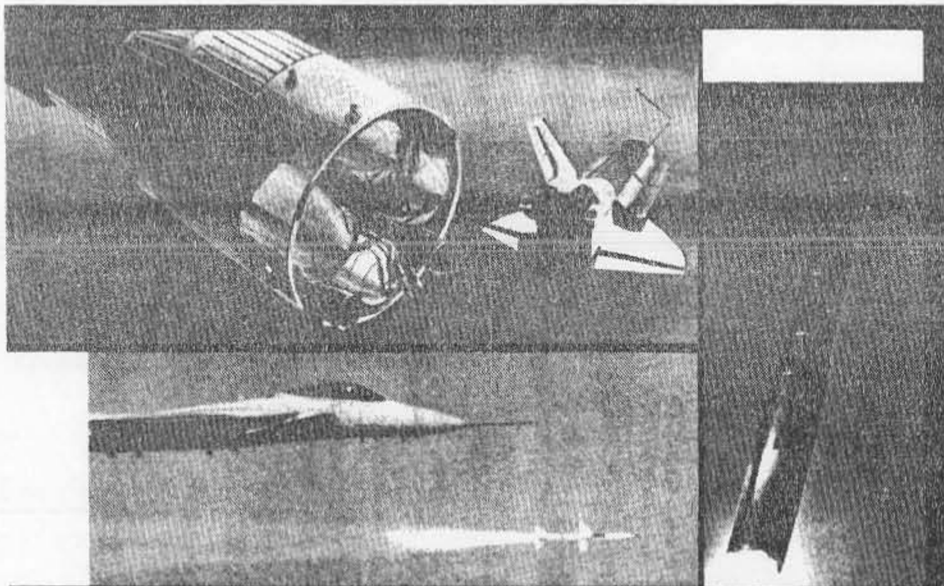
FIGURE 4

Space & Missile Rocket Propulsion (63302F)....



PROJECTS
- Air-Launched Missile Propulsion
- Space Systems Propulsion
- Ballistic Missile Propulsion

FUNDING ($ × MILLIONS)*

FY85	FY86	FY87
2.0	8.4	17.8

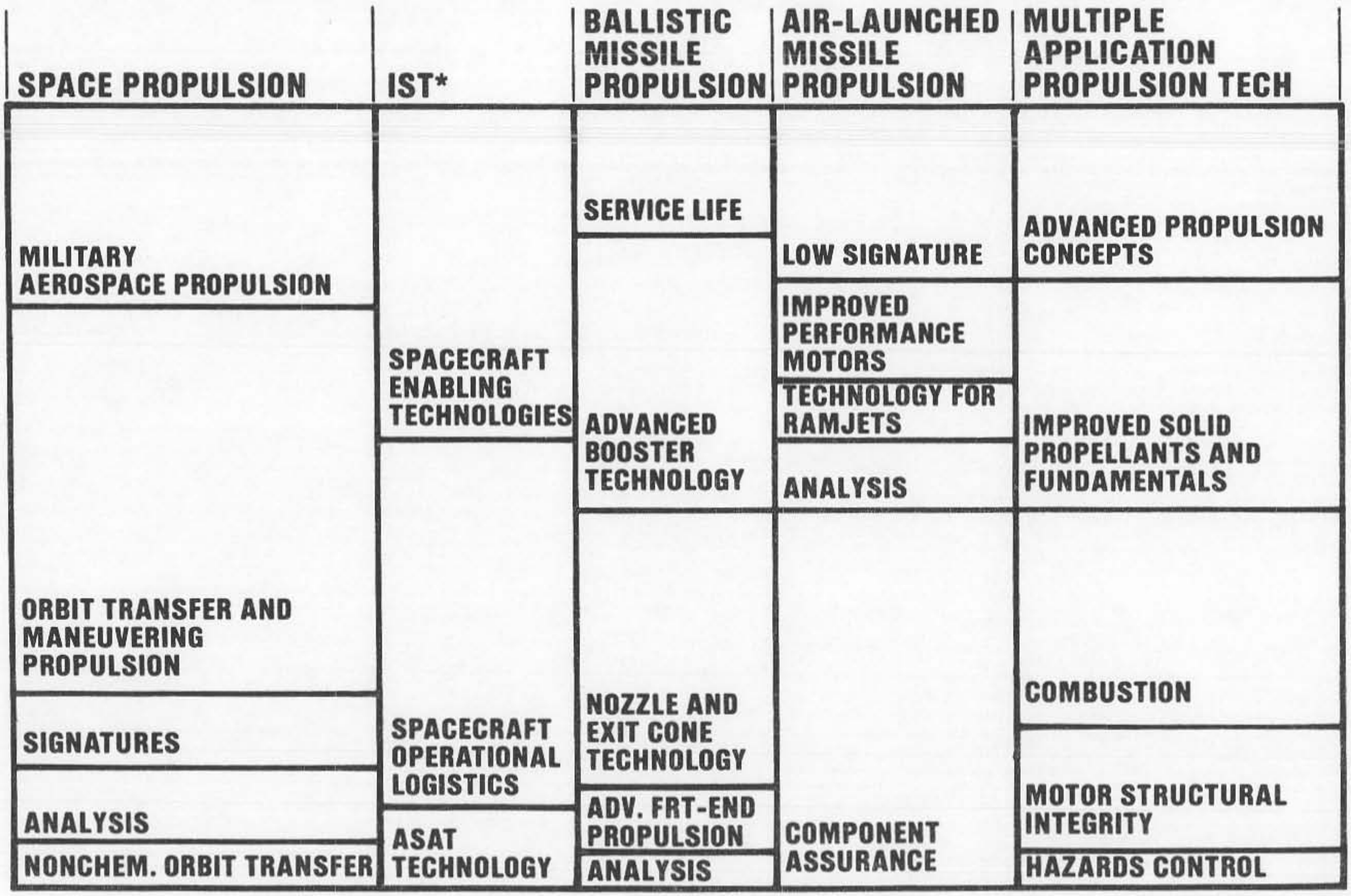
*Based on FY87 POM

PAYOFFS
- Air-Launched Technology
  - Standoff Range Increase
- Space Systems Technology
  - Increased Payload Cap. Over IUS
  - Increased Payload Over Centaur G
  - 31% Length Reduction from Centaur G
- Ballistic Missile Technology
  - Payload Increase Over Present SOA

FIGURE 5

AFRPL Exploratory Development Program....

FY86 (Areas are Proportional to Funding Levels)



*Interdisciplinary Space Technology

00085a

FIGURE 6

AFRPL SDI Focal Points....

SDITO
Dick Weiss

KINETIC ENERGY WEAPONS
Ed Barth/Addison Shostak

WPD's

- KEW 2.4 High Performance MKV Technology
- KEW 2.5* Spaced Based Booster Technology
- KEW 10.1 Space Based KKV Demo
- KEW 2.7 Hi G Projectile

SATKA,LETHALITY,IS&T,OTHER
Maj Ed Huston

WPD's

- SAT-11 LSS Fab Technique
- SL-422 ATP-Fire Control (DEW)
- SAT-32 IR/UV EXO/ENDO Signature
- LTH-403 Particle Beam Lethality

SUPPORT
Lee Meyer/Lt D. Hine

WPD's

- SL 13.1 Space Transport'n
- SPXX Space Power

*Executing Agency

01461

FIGURE 7

TECHNOLOGY PROGRAMS

A discussion of each of the Laboratory's Technical Thrusts is provided in the following paragraphs. The Technical Thrusts will be discussed in the order shown in the upper right quadrant of Figure 4.

1. Space Systems Propulsion Technology

The Space Systems Propulsion Thrust provides technology for all future space systems: launch vehicles, orbit transfer/maneuvering vehicles, and satellites. In addition, as in the past, technology from this thrust will be applied by the Navy, NASA and commercial industry to their space systems. This thrust is summarized and illustrated in Figures 8 through 14.

a. Objectives

The overall Space Systems Propulsion Technology Thrust is broken into five clusters, four are shown in Figure 8. Each of these clusters represent an area in which USAF requirements for advanced propulsion technology are being addressed. The efforts within the clusters are oriented toward achieving the overall thrust objectives shown in the upper left quadrant of Figure 8. The cluster not listed is for propulsion system analyses to evaluate system requirements and propulsion capabilities to evaluate overall system performance improvements.

b. Clusters

Each of the four clusters shown in Figure 8 will be discussed.

(1) Military Aerospace Propulsion

The Military Aerospace Propulsion cluster is summarized in Figure 9. The technology work is aimed at satisfying two key objectives: the delivery of larger, heavier payloads to orbit on a low cost and routine basis and access to space on a survivable, quick turnaround and affordable basis during all levels of conflict. There are three technology areas: engines, feed systems, and propulsion support. For conventional launch vehicles, increased engine performance and lighter weight engines, tanks and feed systems will provide a payload capability beyond that of the Shuttle, while improvements in component fabrication and lifetime improvements will reduce production and maintenance costs significantly. These improvements on expendable and reusable systems will greatly enhance Air Force day to day operations. For launch systems during conflict these technologies will minimize maintenance requirements, simplify ground support interfaces, reduce ground support personnel and allow delivery of meaningful payloads in a survivable manner.

In order to reduce the cost of transporting payloads to low earth orbit, advanced materials are being assessed to determine their applicability to both engine and feed system components. The major goal in applying advanced materials is to reduce the weight of the propulsion system to increase payload capability of the vehicle. Development of technology for rapid-fill of horizontal propellant tanks and engine condition monitoring will provide a capability to quickly turn launch systems around for relaunch. Work in solid propulsion will develop a nozzleless solid rocket booster to lower the overall cost of boosters by eliminating the conventional nozzle hardware.

Space Systems Propulsion....

OBJECTIVES

- Obtain Vehicle Turnaround Time of 20 hours
- 50% More Satellite Maneuvers
- 140-400% More Payload to GEO
- Increase Large Satellite Mission Life to 7 years
- Decrease Number of Sensors Required for Earth Coverage

CLUSTERS

- Military Aerospace Propulsion
- Orbit Transfer and Maneuvering Propulsion
- Nonchemical Orbit Transfer and Satellite Propulsion
- Signatures

FUNDING ($×MILLIONS):

PE	FY85	FY86	FY87
61101F	0.6	0.1	—
62302F	12.5	11.3	12.9
63302F	1.5	4.4	9.7

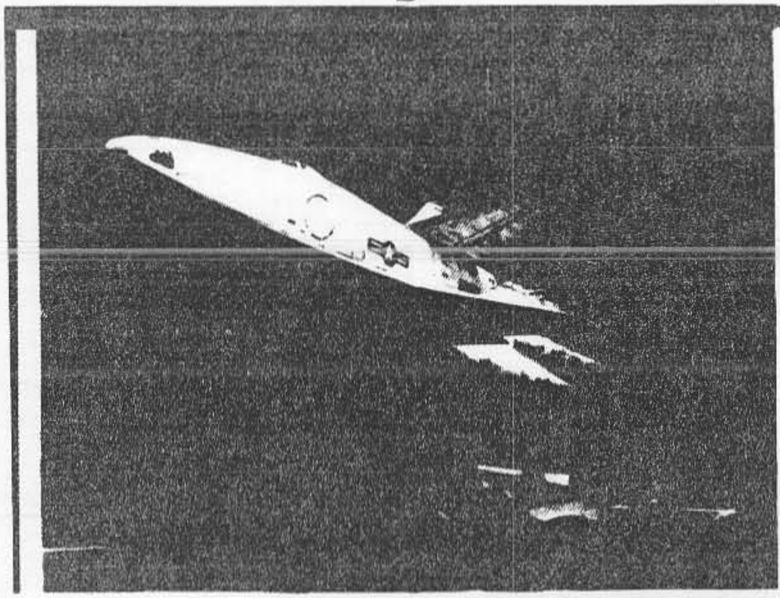
PAYOFFS

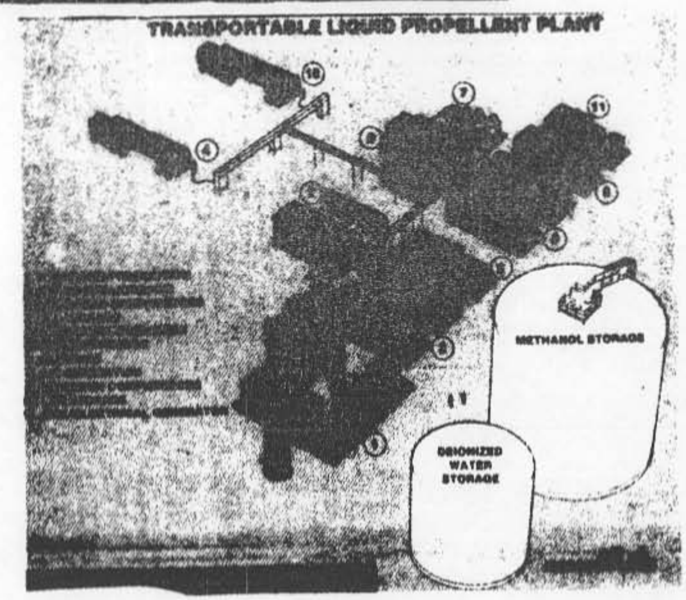
- Provides USAF Space Systems with Rocket Propulsion Technology for:
  - Assured Access to Space
  - Reliable and Effective Space Operations
  - Improved Survivability
  - Affordable Space Systems

FIGURE 8

Space Systems Propulsion

Military Aerospace Propulsion....





- **Propulsion Technology for On-Demand Launch Capability**
  - **Advanced Aerospace Vehicle/MAV/TAV**
  - **CELV**
- **Main Engines**
  - **Turbine Life**
  - **Weight Reduction**
  - **Engine Condition Monitoring**
- **Propellant Systems**
  - **Survivable Propellant Supply**
- **Booster Propulsion**
  - **Low Cost Cryo Tank**
  - **Low Cost Nozzleless Solid Booster**

00107

FIGURE 9

In liquid systems, the capability to assess engine condition in real time will allow maintenance to be performed only as needed. Turnaround time for reusable vehicles can be greatly reduced by eliminating post-flight visual inspections and scheduled maintenance. For Shuttle type engines, the goal is to reduce the turnaround time for relaunch to 20 hours. Conventional launch vehicles will benefit from the overall reduction in operating costs while "on-demand" vehicles will benefit primarily from the time saved in turning the vehicle around, which will be a critical parameter in the viability of these vehicle concepts.

A recent AFRPL study showed that a nozzleless motor concept may lead to low cost systems. A nozzleless motor replaces the nozzle hardware with molded propellant to form the exhaust nozzle. Analysis indicated that this elimination of the the nozzle and its associated support structure results in ten to fifteen percent production cost savings for the solid booster. We are continuing efforts for the demonstration of small and subscale motors (30-48 inch diameters) to assess the nozzleless design scalability to large heavy lift launch vehicles.

(2) <u>Orbit Transfer and Maneuvering Propulsion</u>

This cluster is summarized in Figure 10. As launch vehicle payload capabilities and the value of our space assets increase, complementary improvements in the Orbit Transfer and Maneuvering Propulsion area are needed. As with launch vehicles, the cost of orbit transfer operations needs to be reduced to make them affordable. Also, future space systems will be required to meet stringent survivability needs against projected threats in the post 1990s. Here again, performance, weight and life are key issues, as is volume. Technology efforts are aimed at minimizing the percentage of the transportation system delivery capability that is taken up by the orbit transfer vehicle. High performance cryogenic liquid propulsion technology will enable a range of capabilities, from low thrust, low acceleration transfer of large flimsy space structures to higher acceleration on-orbit maneuvering for satellite survivability.

The Modular Storable Space Propulsion effort includes the demonstration of the XLR-132 engine and its associated propellant feed system. The XLR-132 is an advanced, storable bipropellant (Nitrogen tetroxide/Monomethylhydrazine), high pressure, pump-fed rocket engine currently being developed by the AFRPL. The propulsion system is designed to be a reliable, high performance, multi-application space propulsion system for military operations such as maneuvering and orbit transfer. Along with its advanced feed system, also under development, the XLR-132 will allow a 50 percent increase in satellite evasive maneuvering capability and a 140 percent increase over Centaur G in payload deliverable to geosynchronous orbit. The engine recently completed component evaluation of its gas generator, turbopump, injector, and thrust chamber designs.

The XLR-132 will provide a storable propulsion system for multiple applications. Its compactness will allow it to be integrated directly into satellite system designs for orbit transfer and maneuvering over the lifetime of the satellite. Its modular features will allow it to provide a wide range of propulsion for different satellite sizes and weights. With the XLR-132 the Air Force will have a diverse system which can reduce overall propulsion costs and enhance the survivability of any using system.

Space Systems Propulsion

Orbit Transfer & Maneuvering Propulsion....

- Technology for Orbit Transfer Vehicles and Maneuvering Spacecraft
- Modular Storable Space Propulsion
  - XLR-132 Engine
  - Advanced S/C Feed System
- Cryogenic OTV Propulsion
  - Compact Feed System
  - Low Thrust Engine
- Space Motor Technology
  - Space Storabillity

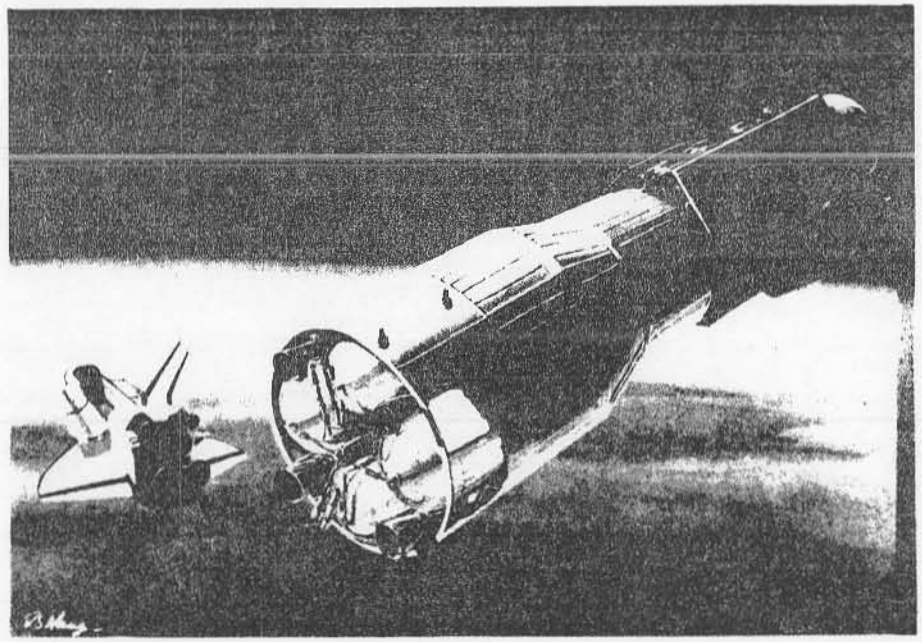


FIGURE 10

The Cryogenic Orbit Transfer Vehicle (OTV) area includes work on a compact propellant feed system and a low thrust turbopump fed cryogenic engine. The Low Thrust Cryogenic Engine along with the Compact Cryogenic Feed System will provide a 36 percent reduction in stage length compared to a wide body Centaur stage. The new cryogenic engine technology will allow for low thrust propulsion, at high performance, for movement of large, fragile, space systems. Future complex satellites with large space structures or appendages will require an initial checkout on low earth orbit to minimize the potential of mission loss. Once carried to low earth orbit by the Space Transportation System the large space system will be erected, and/or assembled, checked out, and then transferred to the operational orbit using the low acceleration of the Low Thrust Cryogenic Engine. The low-g vehicle thrust necessitates a multi-burn transfer scenario and cryogenic propellants for high efficiency. The Low Thrust Cryogenic Engine is currently funded under PE 62302F and will transition to advanced technology development in FY 87.

Detailed design was completed for a toroidal liquid oxygen tank. The "donut-shaped" design will allow the engine to be mounted in the central void of the tank, providing a stage length reduction. The effort, called Compact Cryogenic Feed System, will proceed with demonstration of the tank, and its associated fluid management hardware, for application to the Low Thrust Cryogenic Engine design. The compact system will also be compatible with higher acceleration, RL-10 systems. The Compact Cryogenic Feed System effort transitioned to PE 63302F in late FY 86 to demonstrate the toroidal liquid oxygen tank and its associated propellant management hardware.

We are also pursuing the question of whether solid motors can remain dormant in space and still perform dependably. Once the space storability of solid motors is demonstrated, the lightweight high mass fraction propulsion options available for space systems will be expanded. Confidence in existing performance capabilities will allow satellites to be reconstituted in space, thus enhancing the survivability and effectiveness of satellite systems. In addition, the space arena will be opened to applicaton of compact high energy propulsion to satellite defense systems which can assure space control.

(3) Non-Chemical Orbit Transfer and Satellite Propulsion

The new, Non-Chemical Orbit Transfer and Satellite Propulsion area will provide a stable of propulsion system concepts in order to realize longer lifetimes, higher performance, and propulsion system reliability for both satellite and transportation propulsion. Positioning, maneuvering and stationkeeping, including atmospheric drag make-up, are the types of functions to be performed by the arcjet and solar thermal propulsion concepts emphasized in the next few years. This cluster is summarized in Figure 11.

Due to their lightweight and high performance, electric propulsion and solar propulsion systems used for orbit transfer will provide increased payload delivery to all orbits. The arcjet and magnetoplasmadynamic thrusters promise up to 400 percent more payload capability delivered to geosynchronous orbit than

Space Systems Propulsion

Nonchemical Orbit Xfer & Satellite Prop....

- Nonchemical Technology for Improvements in Orbit Transfer and Satellite Propulsion
- Electric Propulsion
  - Arcjet
  - Pulsed Plasma Thruster
- Solar Thermal Propulsion
  - Concentrators

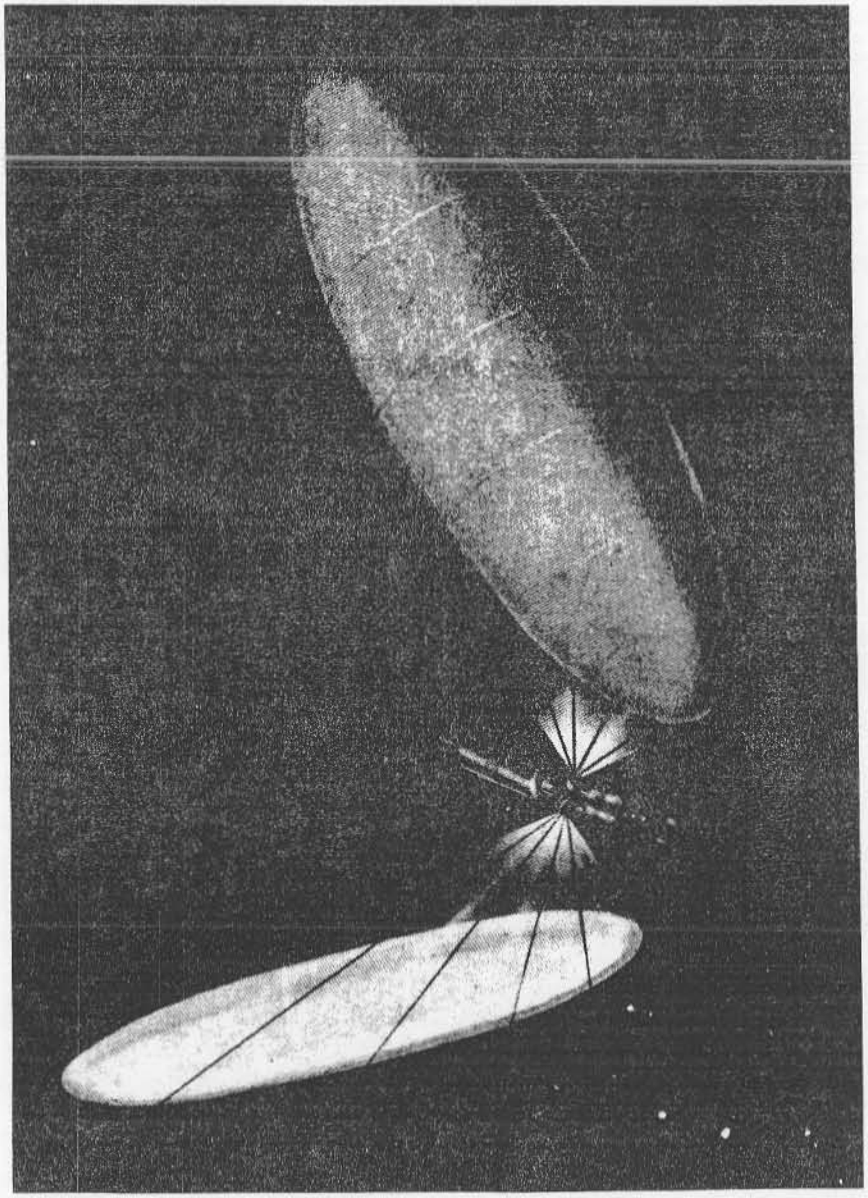


FIGURE 11

currently possible with the Centaur G. The arcjet can provide dual payoff as it can be used for long term secondary propulsion needs which can enhance the lifetime and survivability of space systems. The solar thermal propulsion can provide up to 142 percent payload increases with an intermediate transfer time on the order of tens of days.

The Arcjet Propulsion effort undergoing life testing in FY 86 under PE 62302F will start advanced development in FY 87. The construction and demonstration of a flight ready 30KW arcjet under PE 63302F will include a space experiment in conjunction with the Space Test Program for flight in FY 89.

(4) Signatures

The signatures cluster is focused on the development of analytical tools which enable the prediction of rocket exhaust plumes observable phenomena. These predictions are based on the characteristics of the propulsion system and the exhaust products which it produces. In order to develop the analytical tools or models, fundamental data must be obtained in various areas such as gas dynamics and radiation physics. This data is then used as the basis for the prediction computer codes. Once the codes have been generated, their predictions must be compared with the measurements of actual rocket firings in order to assess their accuracy. The end product is a set of tools which can be used to support the development of sensors and data-processing algorithms for the surveillance and tracking of missile launches around the world, as well as for extraction of intelligence data from launch observations. This cluster is summarized in Figure 12.

c. Payoffs

Figure 8 shows some of the payoffs that can be realized through the application of rocket propulsion technology to future Air Force space systems. Figure 13 lists representative systems to which the technologies in this thrust can transition. There are many technologies involved, from advanced engines to thermal analysis for cryogenically-fueled OTVs, to optics and acoustics for engine condition moonitoring, to gas dynamics and radiation physics for exhaust plume signature characterization.

d. Funding

The table in Figure 8 shows the total funding that we plan to devote to the Space Systems Propulsion Technology Thrust through FY 87. Program Element 61101F is the Laboratory Director's Independent Research Program, Program Element 62302F is for Exploratory Development, and Program Element 63302F is for Advanced Technology Development.

e. Future Plans

Planned future areas of work within the Space Systems Propulsion Technology Thrust are listed in Figure 14.

2. Interdisciplinary Space Technology

Interdisciplinary Space Technology focuses on integration of multiple disciplines to produce technology which provides the link between key propulsion and non-propulsive components of space systems in order to develop a total system. This thrust is illustrated and summarized in Figures 15 through 20. Efforts in this thrust

Space Systems Propulsion

Signatures....

- **Technology for Prediction and Manipulation of Rocket Exhaust Observables**
  - **Surveillance**
  - **Intelligence**
- **Fundamental Properties**
  - **Radiation Mechanisms**
- **Modeling**
  - **Fuel Vent Model**
  - **High Altitude Radiation Code**
- **Model Verification**
  - **Ground and Flight Data**

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FIGURE 12

Space Systems Propulsion

Transition Targets....

- Advanced Aerospace Vehicle (MAV/TAV)
  - Main/Auxiliary Propulsion, Propellant Tanks and Supply
- Defense Support Program
  - Integral Maneuvering Propulsion
  - Target Prediction
- Advanced Upper Stages/IUS, Reusable OTV
  - Orbit Transfer Propulsion
- GPS, DSCS
  - Orbit Transfer & Maneuvering Propulsion
- Space-Based Radar
  - Lightweight, Precise Attitude/Position Control Propulsion
- ASAT
  - Booster Propulsion

00112

FIGURE 13

Space Systems Propulsion

Future Plans....

- Application of Advanced Materials to Launch Vehicle Engines & Feed System
- Develop Military Propellant Production Capability
- Reusable, Lightweight Launch Vehicle Feed System
- Reusable XLR-132 Engine/Feed System
- Flightweight, Low Thrust Cryogenic Engine/Feed System
- MPD Life Testing
- Ultraviolet Plume Radiation Modeling

FIGURE 14

fall under three areas: Spacecraft Enabling Technology, Spacecraft Operational Logistics, and ASAT Technology.

a. Objectives

As shown in Figure 15, the intent of this thrust is to provide advanced technologies which will allow the U.S. to do a great many more things in space and to do these things at lower cost and free of obstruction from aggressive enemy action. Seventy-five percent reduction in radiator weight and the ability to control large space systems will enable the deployment of such systems as Space Based Radar and Space Based Laser. A 40 percent increase in satellite life can be achieved with contamination minimization. This, among other technologies for increasing satellite life, will lower the overall life cycle costs of space operations. Advancements under ASAT technology will augment combined range and altitude capabilities of air-launched boosters by a significant percentage which will enhance our ability to protect our space systems.

b. Clusters

Each of the three clusters shown in Figure 15 will be discussed.

(1) Spacecraft Enabling Technologies

The growing need for space systems in the role of space control, force enhancement, and force application calls for several concepts that are very large, require great quantities of power and call for, in general, a more survivable architecture. Examples of spacecraft enabling technologies being pursued at the Laboratory are summarized in Figure 16. These technologies will enable major capability increases in USAF systems.

System concept descriptions in planning documents, such as the "Military Space Systems Technology Plan," will require power levels exceeding one megawatt. Since no system can be 100 percent efficient, there will be extremely large amounts of waste heat produced. The size and weight associated with conventional space radiators would be enormous for such systems. Additionally, huge amounts of heat will be exchanged between several of the high power subsystems. Depending on the temperature level, the size of the heat exchanger devices required for extensive heat loads can be very massive. The Space High Power Heat Transer area is therefore focused on providing the technology needed to meet future high power thermal control requirements with minimum system weight and volume penalties. We are jointly pursuing the Liquid Droplet Radiator (LDR) concept with the NASA Lewis Research Center to enable multi-megawatt space systems. The challenge here is to minimize the fluid loss in order to minimize the amount of reserve fluid that needs to be carried into orbit and the amount of contamination that the radiator may impose on the spacecraft.

We recently demonstrated in a vacuum that a passive collector (no moving parts) can capture and repressurize multiple droplet streams. We will continue with an integrated program to develop the LDR components and by FY 89 begin a space experiment to demonstrate its capability in space.

Interdisciplinary Space Technology....

OBJECTIVES

- 75% Reduction in Radiator Weight for High Power Space Systems
- 40% Increase in Satellite Life
- Enable Large USAF Space Systems
- Increased ASAT Capability

CLUSTERS

- Spacecraft Enabling Technologies
- Spacecraft Operational Logistics
- ASAT Technologies

26

FUNDING ($×MILLIONS):

PE	FY85	FY86	FY87
61101F	0.1	—	—
62302F	3.6	6.4	7.0
63302F	—	—	1.0

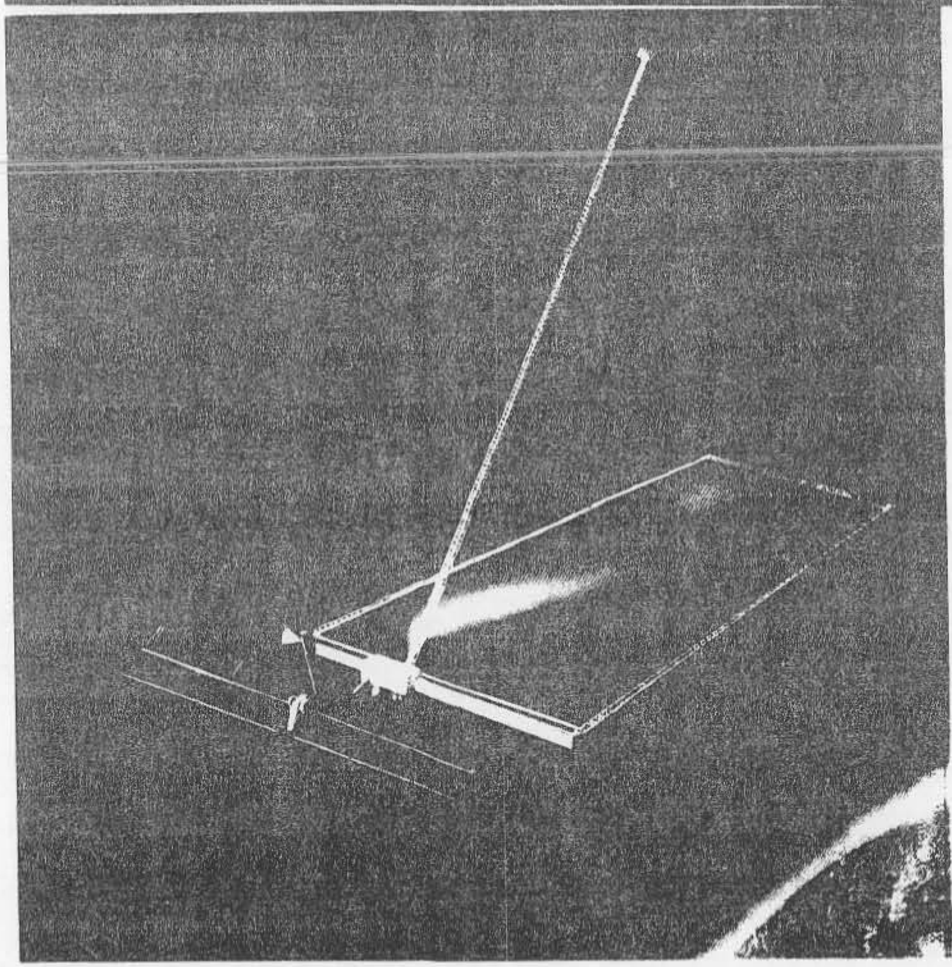
PAYOFFS

- Increased Spacecraft Survivability
- Lower Cost Space Operations
- Enhanced Space Superiority and Control

FIGURE 15

Interdisciplinary Space Technology

Spacecraft Enabling Technologies....



- Enabling Technologies for Future Air Force Space Systems
- Space High Power Heat Transfer
  - Liquid Droplet Radiator
  - Direct Contact Heat Exchanger
- Large Space Systems Dynamics and Control
  - Flexing Structure Control
  - Deployment Dynamics
- Spacecraft Autonomy
  - Automatic Isolation

27

FIGURE 16

Within the future Air Force space architecture will be "Large Space Systems," larger than anything yet put into space (as much as hundreds of meters in diameter in length). In order to make it possible to lift these platforms into orbit, however, they must be extremely light, and be either deployed or assembled on-orbit. As a result, they will be unprecedented in flexibility and complexity of the attitude/shape control system. This complexity will be compounded for some systems by a requirement of rapid slewing. The technical needs of Large Space Systems addressed in this area are deployment, shape identification, rapid slewing, small angle retargeting, and vibration control; including high frequency vibration supression.

The large space systems technology area will provide advances related to structural control actuators and corresponding control laws, algorithms for driving these actuators, and deployment simulation capabilities to support actuator and control algorithm development. All of these areas are challenging. Deployment, for example, will involve significant mass flow (as in mesh unreeling from a roller) and ring structures and it will be difficult to simulate these in a general code, as is our objective. Successfully modelling deployment will enable a reduction in the number of experiments required to achieve confidence in large space structure deployment.

The autonomous operation of a satellite will promote a longer natural satellite life as well as extend its operation under varying levels of conflict. Software which can characterize and predict satellite anomolies will enable satellites to make more of their day-to-day decisions and perform routine functional assessments, making them less dependent on ground sites which will be vulnerable during hostilities. The autonomy area is also geared toward mobile satellite ground terminals, where there will be less manpower and equipment to support the spacecraft. Recently, AFRPL advanced algorithms detected and identified a sun shutter anomoly from satellite telemetry. In the next few years, our work in autonomy is centered on an automatic propellant leak detection and isolation system. Using acoustic sensors, small propellant leaks which could otherwise lead to the demise of an entire satellite, can be detected. The leak can then be isolated from the rest of the system enabling the spacecraft to continue a partially limited but useful life.

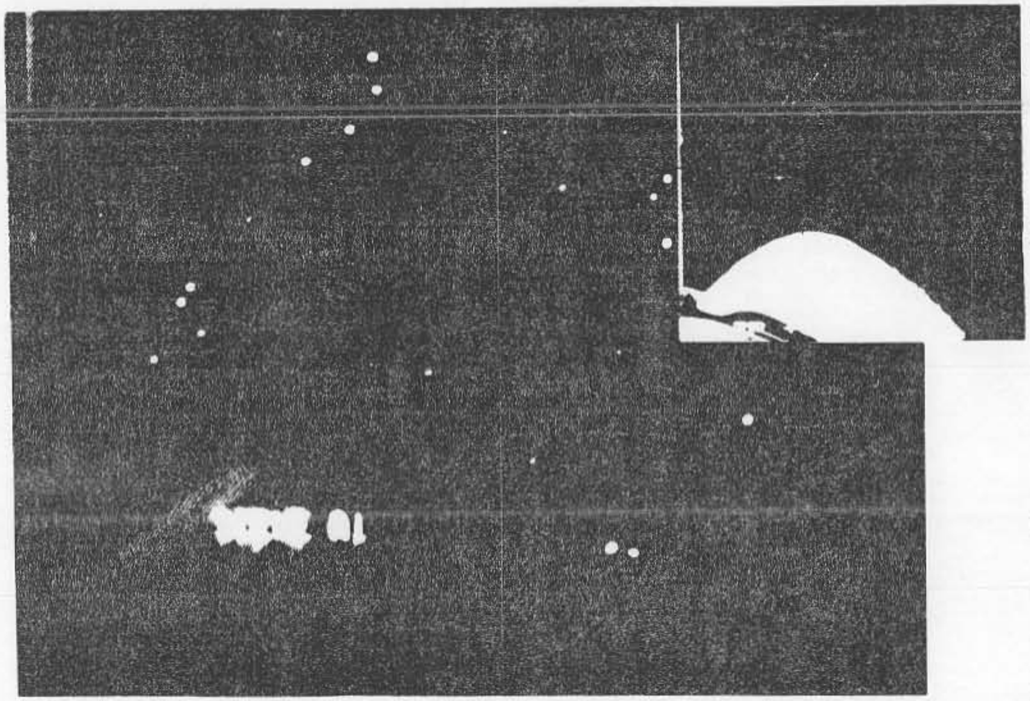
(2) Spacecraft Operational Logistics

The expanding role of space in defense, will mean significant space operations. Examination of operations exposes critical technical needs which must be adressed to allow viable, flexible, enduring and affordable space exploitation. The interdisciplinary technology areas addressed in this area include contamination, reuse and resupply, and long term cryogenic storage. These technologies are summarized in Figure 17.

Over the course of a satellite's life, it is exposed to both the "natural" space environment and an "induced" environment. Many sources contribute to this induced environment, including exhaust products from orbital insertion and attitude control propulsion systems, outgassed vapor from electronics, and thermal control materials/coatings, propellant leaks, etc. Such materials can deposit on sensitive spacecraft surfaces such as optics, solar arrays or radiators, and degrade their critical properties. These "contaminants" originate not only from the satellite itself, but from upper stages and the Shuttle as well. Contamination can degrade a spacecraft sub-system to the point of making it useless. This, in turn,

Interdisciplinary Space Technology

Spacecraft Operational Logistics....



- Technology for Satellite Lifetime and Survivability Enhancement
- Spacecraft Contamination
  - Database Management
  - Contamination Models as Design Tools
- Reuse/Resupply
  - Venting Components
- Long Term Cryogenic Storage
  - Thermal Management

FIGURE 17

can render the entire spacecraft useless, years before its design life has expired. In the contamination area, we are developing technologies to characterize various sources of contaminants and their effects on satellite surfaces, analytical tools to predict the amount of contamination and its effects given a particular spacecraft design, design techniques to minimize the amount of contamination that will deposit on sensitive surfaces, and on-orbit "cleaning" techniques for those surfaces which cannot be protected from contamination.

Future Air Force space needs will include the resupply of propellants to satellites as well as the reuse of orbit transfer vehicles. The life of some satellite systems is limited solely by the propellant quantities which are limited by weight and volume constraints imposed by transportation cababilities. By resupplying satellites their useful life can be greatly enhanced. Resupply, however, is not a simple task as it is complicated by the zero-g environment. Reuse of orbit transfer vehicles, space-based or ground-based, may ultimately reduce the cost of the deployment task. The definition of such a vehicle and its mode of operation is a significant challenge and will no doubt be affected by the developing space architecture. Our efforts in reuse and resupply will entail identification and development of fluid management techniques and resupply operations assessment. With the addition of reuse and resupply capabilities, mission flexibility and reliability and maintainability will be increased.

The feasibility of several Air Force space missions, including space basing of reusable orbit transfer vehicles, and a future space-based radar, depends strongly on achieving the ability to store large quantities of cryogenic fluids in space for several years. The space based orbit transfer vehicle will need a continuous supply of propellant while high power systems, like a future space-based radar, will require a lifetime supply of cooling fluid. Among the wide range of critical technology developments and technology improvements to meet this challenge, thermal insulation, and cryogenic passive cooling are two of the most important candidates. Together, as an integrated thermal control system, these two technologies offer both lower development risk and superior performance in terms of thermal control, weight penalty, system simplicity and reliability and costs. In the Long-Term Cryogenic Storage area, we will focus on development and demonstration of performance of the various components in the thermal insulation area and the cryogenic passive cooling area.

(3) Anti-Satellite (ASAT) Technology

The survivability of our space satellites will depend in part on our ability to preclude free space operation by aggressive enemy systems. The objective of the Anti-Satellite Technology area is to idenitfy, design, develop and demonstrate new and innovative ASAT technologies. The advancements are aimed at pre-planned product improvement for the present ASAT and for succeeding, next generation ASATs. Present emphasis is centered at improvements in performance, maintainability, reliability, storability, lethality, and survivability. The technologies of this area are summarized in Figure 18. To obtain these technology advancements, improvements are required in propulsion systems, both booster and projectile, of space weapons, the design and development of advanced warhead concepts and the identification and implementation of alternate component materials and manufacturing processes. Among the efforts will be an air-launched ASAT solid motor booster improvement program, which will adapt technologies

Interdisciplinary Space Technology

ASAT Technology....

- **Enabling Technologies for Space Control**
- **Space**
  - **Booster Propulsion**
  - **Projectile Propulsion**
- **Advanced Reaction Control Motor Technology**
- **Air-Launched ASAT Booster Improvement ATD**
- **Innovative, Advanced Designs**

FIGURE 18

developed for ICBM and space motors, such as composite cases, high energy propellants, and carbon-carbon nozzles, to the harsher air-launched missile environment. It is these technologies when combined which can bring about a significant percentage altitude/range extension in ASAT capabiity. With the various advancements in this ASAT Technologies area, overall costs can be reduced by minimizing weight on orbit and reducing the need for extremely accurate guidance systems.

c. Payoffs

Figure 15 shows some of the payoffs that can be realized through the application of the interdisciplinary space technology of this thrust area. Figures 19 and 20 lists representative systems to which the technologies of this thrust could transition. Many of the technologies are high risk, high payoff areas. However, without these technologies, many of the complex future systems that are projected today will not be possible. Their advancement will require the participation of a broad spectrum of government and industry organizations and people.

d. Funding

The table in Figure 15 shows the total funding for this thrust through FY 87. Program Element 61101F is the Laboratory Director's Independent Research Program, Program Element 62302F is for Exploratory Development and Program Element 63302F is for Advanced Technology Development.

3. Air-Launched Missile Propulsion Technology

The Air-Launched Missile Propulsion thrust develops the propulsion technology needed for air-to-air and air-to-surface missiles. This technology will provide future missile systems with the following benefits: increased survivability, increased lethality, increased reliability, increased age life, and increased cost effectiveness. The principal areas of emphasis are an understanding and manipulating of plume signatures, improving performance and providing energy management. Technology from this thrust has also been adapted by the Navy and Army in their tactical missiles. This thrust is illustrated and summarized in Figures 21 through 24.

a. Objectives

The overall objectives of this thrust are presented in Figure 21. The operational benefits being provided in signature, survivability, range, and fire power are necessary in order to overcome the numerical superiority and increased threat our forces are facing. By reducing our missile signatures (infrared, ultraviolet, visible and radar) and improving missile performance we will increase missile flexibility and lethality. These missile improvements, added to increases in standoff range and fire power equate to increases in aircraft survivability and mission performance (e.g. more munitions on target, more kills per pass, higher sortie rates, etc.). As the above operational benefits are being provided, it is also a major objective to provide logistics benefits in reliability, age life and cost. The work in this thrust is performed under five sub-thrusts or clusters as outlined in Figure 21.

Interdisciplinary Space Technology

Transition Targets....

- Defense Support Program (DSP)
- Defense Meteorological Satellite Program (DMSP)
  - Increased Survivability/Autonomy
  - Decreased Contamination
- Global Positioning System (GPS)
  - Increased Survivability/Autonomy
- Milstar
  - Increased Survivability/Autonomy
  - Likely to Evolve into Survivable Satcom
- Advanced Surveillance System (Optical)
  - High Survivability/Autonomy
  - Low Contamination
- Space-Based Radar (SBR)
  - Tight Surface Control
  - Waste Heat
  - Maintenance
- Air-Launched Anti-Satellite (ASAT)
  - Increased Capability

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FIGURE 19

Interdisciplinary Space Technology

Transition Targets (Cont'd)....

- **Space-Based Weapons**
  - Jitter/Structural Response
  - Waste Heat
  - Contamination
  - Survivability/Autonomy
  - Maintenance
  - Reuse/Resupply
  - Innovative Warhead Concepts
  - Long Term Cryogenic Storage
- **Satellite Defense System (SDS)**
  - Contamination
  - Survivability/Autonomy
- **Reusable Orbit Transfer Vehicle**
  - Autonomy
  - Contamination
  - Long Term Cryogenic Storage
  - Reuse/Resupply

FIGURE 20

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Air Launched Missile Propulsion....

OBJECTIVES

- Provide Propulsion Technology to
  - Reduce Missile Signature
  - Increase Missile Survivability
  - Increase Standoff Range
  - Increase Firepower
  - Improve Reliability & Age Life
  - Reduce Missile Cost

CLUSTERS

- Low Signature
- Improved Performance Motors
- Technology for Ramjets
- Propulsion Analyses
- Component Assurance

FUNDING ($×Millions)

PE	FY85	FY86	FY87
62302F	5.6	7.5	8.8
63302F	0.5	2.0	4.9
62203F	0.3	1.1	1.3
Other	0.5	0.7	0.9

PAYOFFS

- Range Increase/No Escape Zone
- Weapons Loadout Increase
- Lower Missile/O&M Costs
- Reduced Missile Propulsion Wt 20%
- Increased Missile/Aircraft Survivability
- Decreased Carriage Drag

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FIGURE 21

b. Clusters

The first cluster involves "Low Signature Motors." This cluster addresses low signature propellant development and plume analysis for air-launch systems. The objectives are to improve the performance and reduce the costs and hazards of minimum signature propellants and to predict, analyze and minimize plume signatures. Minimum smoke propellants provide increased aircraft survivability and missile lethality. In Europe, minimum smoke propellants form no contrail below 27,000 feet, whereas reduced smoke propellants form contrails 50 percent of the time below 20,000 feet. All state-of-the-art minimum smoke propellants have a class 1.1 hazards classification. These 1.1 propellants may not be used in Europe due to limiting quantity distance requirements for storage and increased risk in daily operations. This points out the critical need for reduced hazards 1.3 minimum smoke propellant development and demonstration. Technology areas being investigated to provide improved plume prediction and analysis are, (1) development of a means to analyze the plume such that realistic particle parameters may be obtained, coupled with (2) validation of existing computer codes to accurately predict rocket observables.

The goal of the second cluster "Improved Performance Motors" is to investigate and develop new technologies, or optimize the use of current technologies, in order to improve the performance of motors for air-launched missiles. The programs in this cluster will result in motors with high mass fraction (2-3 percent higher than current state-of-the-art), significantly reduced drag (25 percent reduction), reduced observables and increased maneuvering. As a bottom line, this means more missile range for less motor weight as well as increased lethality of the missile. Technology areas being investigated to provide this improved performance include: Propulsion Packaging Flexibility, which provides more efficient motor packaging for high lift/low drag missile designs; Thrust Controllability, which provides for thrust vectoring and thrust modulation with a payoff in terms of reduced drag and increased lethality, Optimal Control, which provides a logic for on-board, real-time calculation of the best use of available propulsion; and High Pressure Operation, which provides for the substantial payoffs in terms of propulsion energy (8-10 percent) associated with operating rocket motors at high pressures.

The third cluster is support "Technology for Ramjets." Responsibility for the development of ramjets lies within the Aero Propulsion Laboratory. However, ramjet operations depend upon solid rocket boosters to provide initial missile acceleration before ramjet takeover. It is the goal of this cluster to provide improvements in solid rocket technologies and the interfaces between the rocket and ramjet components. A short term goal is to reduce the booster volume while maintaining or improving the thrust level. This is being accomplished through the development of nozzleless boosters, increased performance propellant, and improved insulation.

"Propulsion Analysis" is the fourth cluster. The goal is to evaluate system requirements and propulsion capabilities to determine missile performance. This information is invaluable in directing technology developments for the future. Integrating various technology improvements with analytical models yields a figure of merit for achievable payoff gains.

The fifth cluster is "Component Assurance." The purpose of this cluster is to ensure that the major new components under development meet the air-launched goals for service life, load fatigue, handling, and reliability. Principal efforts include projects in composite case durability and damage assessment, laser arm/fire devices, laser igniters, and motor surveillance methodology. The payoff of these programs will be on the "ilities" improvements during operational air-launch missile motor usage. In the motor case technology area, projects are oriented to solve the problem areas which include composite case attachments, composite case design, composite case durability, and development of high temperature resins (above 1,000°F). In the igniter-arm-fire-device (AFD) area the emphasis is to adapt the previously demonstrated breadboard device to pulse motors. The objective is to demonstrate an aircraft mounted reusable AFD to replace the current non-reusable AFD required for each missile. Improvements in safety and reliability should be realized. In the motor surveillance area an aging program on minimum smoke propellant service life will continue. In addition, a cumulative damage assessment will begin for high strain motors. The FY 86-88 programs for the above clusters are summarized in Figures 22 and 23.

c. Payoffs

Specific payoffs available from air-launched missile propulsion are summarized in Figure 21. Range increases can be achieved through lower motor case weights, higher operating pressures, and solid propellant grain configurations when used with optimal logic controls. The increase in loadout is very important for more missiles per sortie. This will be achieved with conformal shaping and reduction/elimination of fin controls; development of thrust vector controls will negate the necessity for large fins. Decreased signatures result from advances in propellant formulation technology. In addition, the component assurance area will result in greater reliability, maintainability and lower O/M costs.

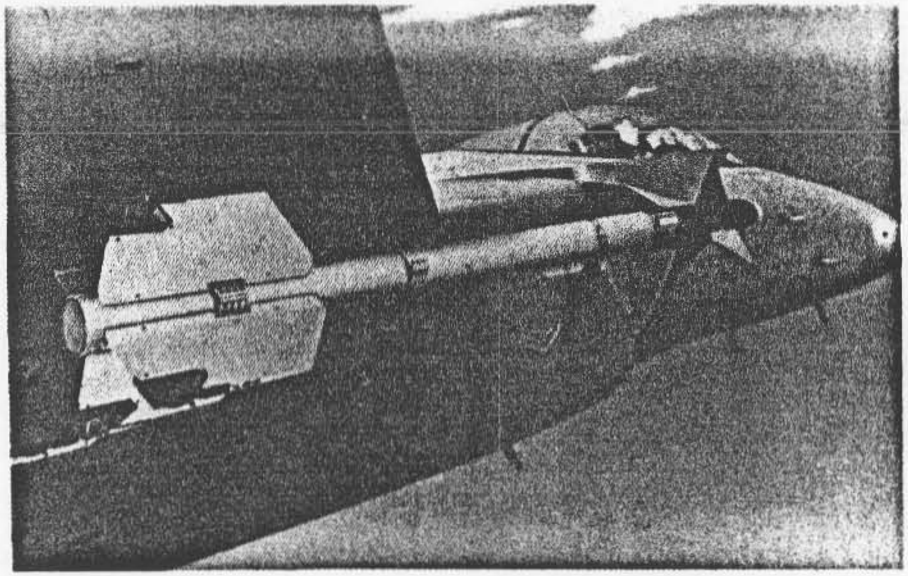
All of the above technology advances need to be demonstrated in flight demonstrations. A joint AFATL-AFRPL-AFWAL program is designed to do this and is shown in Transition Targets (Figure 24). This is a very important program for all future air-launched systems. The modular features of the Advanced Missile Technology Integration (AMTI) test bed allows new components to be tested alone or in combination with other new components. In the rocket propulsion area, the leading edge technology to be tested in AMTI Phase I will be motors with a two-pulse capability to validate servicability. Propulsion technologies for Phase II AMTI will include 1.3 minimum smoke propellant, advanced TVC, laser initialed AFD, filament wound graphite composite case with high temperature resins capable of 2,000 psi operating pressures, multi-dimensional carbon-carbon integral throat entry nozzle, and optimal energy management logic. These technologies are the forerunners of spectacular gains that will be achieved in future air-launched missile systems.

d. Funding

Figure 21 shows the total funds to be expended in the Air-Launched Missile Propulsion Technology thrust from FY 85 through FY 87. Program element 62302F is for the exploratory development efforts under Project 3148. Program Element 63302F covers the completion of an Advanced Technology Development (ATD) effort under Project 6339 to demonstrate advanced technologies in pulse motors,

Air-Launched Missile Propulsion

FY86 Program....



- High Press/Low Rate Propellant
- 1.3 Min Smoke Propellant Demo
- Nonsymmetrical Motor Case
- Service Life Model Verification
- Resin Process Development
- Composite Case Damage Assessment
- A/L Missile Analysis Code Development
- Ignition System for Ramjet Boosters
- High Performance/Low Observables (6.3)

FIGURE 22

Air-Launched Missile Propulsion

Future Plans FY87-88....

- 1.3 Minimum Smoke Motor Demonstration
- High Pressure/High Rate Propellant Development
- High Pressure Nozzle Development
- End Game Optimal Control Investigation
- Low Shock Consumable Igniter Development
- Cumulative Damage Assessment for High Strain Motors
- Laser Arm-Fire Device for Pulse Motors
- Solid Fuel Ramjet Booster Development
- Advanced Insulation System for Ramjet Boosters

FIGURE 23

Air-Launched Missile Propulsion

Transition Targets....

- Radial Pulse Motor
  - 6.5" and 7" to AMTI Phase I
  - Validate Serviceability
- Advanced Air-Launched Motor
  - Composite Case/Pulse Motor to SRAM II
- High Performance/Low Observables
  - To AMTI Phase II
  - 1.3 Min-Smoke Propellant
  - Reduced Fin Area and TVC
  - Laser-Initiated AFD
  - Advanced Composite Case
  - Optimal Energy Management Control

FIGURE 24

thermal barriers and composite cases. Also included in the 63302F area is the start of an effort directed toward future air-launched missiles that will be integrated into the Phase II AMTI program. The 62203F effort is all the work supporting ramjet booster propulsion. Other funds are received to support ongoing system developments such as AMRAAM, AGM-130, HVM, SRAM-II and SPW.

4. Ballistic Missile Propulsion Technology

The Ballistic Missile Propulsion Technology thrust contains five clusters to develop technology for future USAF ballistic missile booster systems, upper stages and payload delivery systems. This thrust is illustrated and summarized in Figures 25 through 30.

a. Objectives

The overall objectives include developing technologies that will increase booster reliability, enhance service life capability, reduce operation and maintenance costs, and increase payload and range while reducing missile size. These objectives will be met by investigating critical areas of solid propellant motor failure modes such as bonded interfaces, chemical migration and propellant aging. Components are being developed that will reduce the weight and volume of future ballistic missiles. New and innovative nozzle designs, simple and economic processing techniques and characterization of nozzle performance and materials will increase reliability and reduce costs for future nozzle and exit cone systems. The work in this thrust is performed under five clusters as shown in Figure 25.

b. Clusters

The Ballistic Missile Service Life cluster (Figure 26) is responsible for developing technologies that will increase booster reliability, enhance service life capability and reduce operation and maintenance costs. This is accomplished by investigating, identifying and providing technology for controlling the processes which may lead to a high probability of failure in critical areas in a solid rocket motor. Bonded interfaces are being investigated to acquire technology to direct the development and evaluation of structurally superior bonded interfaces. Manufacturing and processing variables of high energy propellants will be investigated in order to identify and develop procedures that will ensure the production of reproducible propellants, liners, insulations and bond systems. Sensitive and automated computed tomography non-destructive evaluation technology is being applied to identify the effects of defects, and to guide in the development of accept/reject criteria for solid rocket motors. This developing technology will improve reliability and service life capability of solid rocket motors.

The Advanced Booster Technology cluster (Figure 27) is responsible for developing solid rocket motor components that provide growth capability for future ballistic missiles in terms of throw-weight or range, while reducing the size and life cycle cost of the booster. Motor case development is underway that will reduce the inert weight by introducing advanced Kevlar or graphite fibers with low density resins. Case efficiency and reliability are areas of special emphasis. Work is continuing on the development of the Integrated Stage Concept to reduce system weight and/or increase payload. High pressure, high burn rate propellant development will begin for the fast-launch ICBM ballistic missile concept. Work on low cost thrust vector actuation is planned in the near future. The objective is to simplify the actuation system while decreasing the weight and increasing the reliability.

Ballistic Missile Propulsion....

OBJECTIVES

- Provide Propulsion Technology for Future USAF ICBM Systems to:
  - Assure Survivable, Enduring Strategic Forces
  - Provide Remote Surgical Strike on Fixed Targets

CLUSTERS

- Ballistic Missile Service Life
- Advanced Booster Technology
- Nozzle & Exit Cone Technology
- Advanced Front-End Propulsion
- Ballistic Missile Propulsion Analysis

FUNDING ($×MILLIONS):

PE	FY85	FY86	FY87
61101F	.050	—	—
61102F	0.17	.224	.188
62102F	0.19	.150	—
62302F	5.2	6.4	7.4
63302F	—	2.0	3.2
64312F	.557	.465	.405
64609F	0.80	1.1	2.6

PAYOFFS

- Range Increase
- Throw-Weight Increase
- Reduced In-Process Rejections of Nozzles and Exit Cones
- Lower Risk Nozzle Systems
- Increased Service Life & Operational Capabilities
- Enhanced Survivability/Multiple Basing Modes

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FIGURE 25

Ballistic Missile Propulsion Service Life....

- **Computed Tomography of Solid Rocket Motors**
- **Bonded Interface Technology**
- **Bond Test Specimen Design/Evaluation**
- **SICBM Structural Analysis**

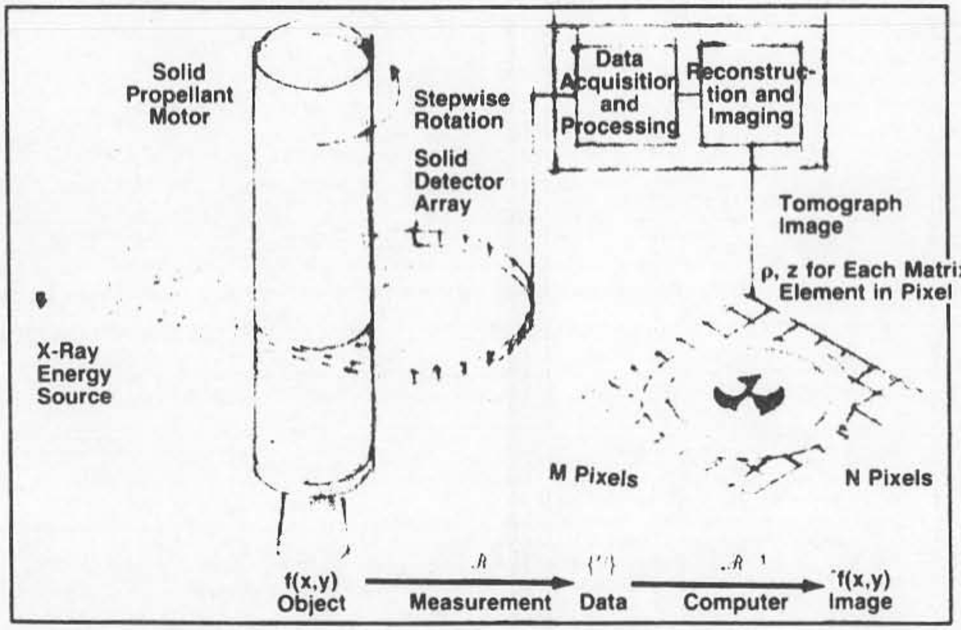


FIGURE 26

Ballistic Missile Propulsion Advanced Booster Technology....

- Lightweight Composite Case
- Integrated Stage Concept
- Fast Launch ICBM Propellant Development
- Low Cost Thrust Vector Actuation System

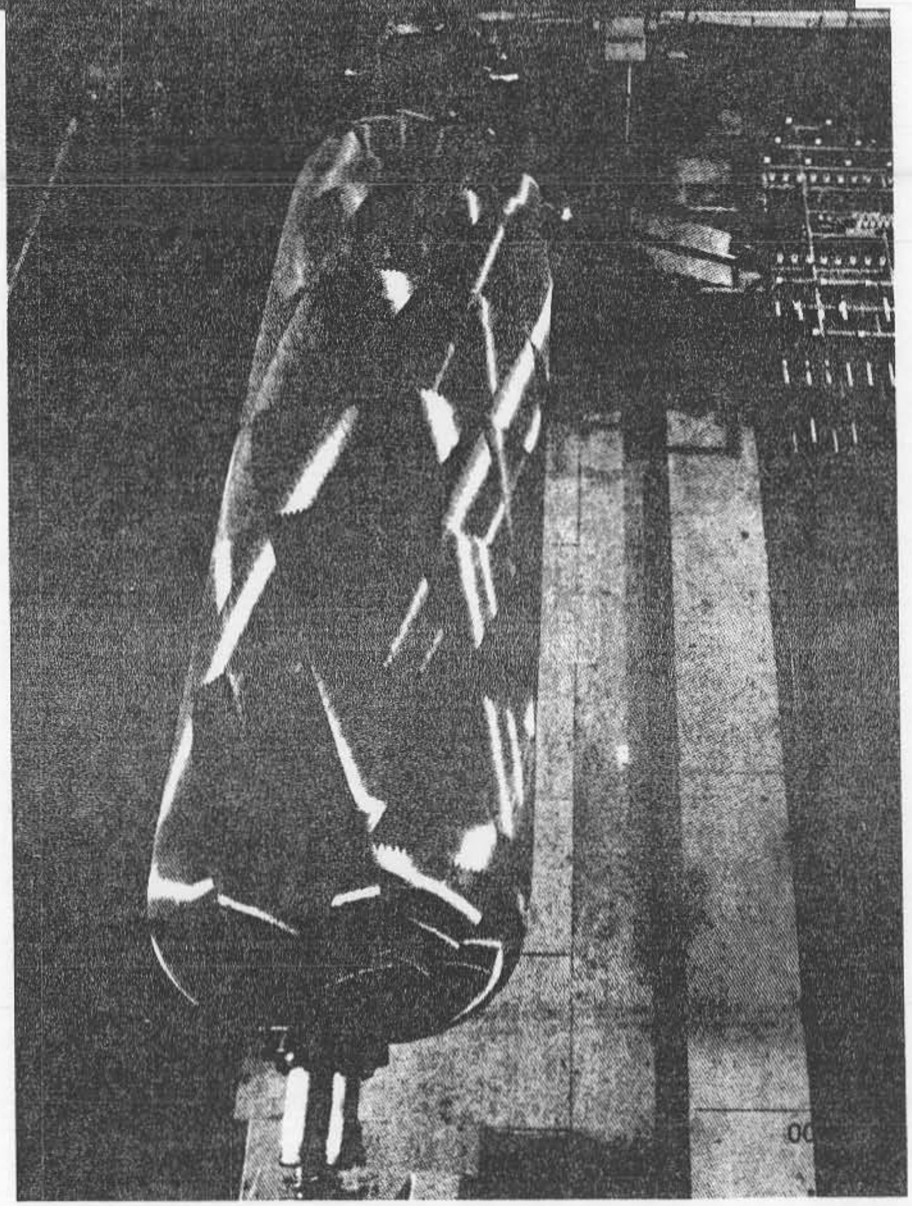


FIGURE 27

The Nozzle and Exit Cone Technology cluster (Figure 28) develops nozzle components for future ballistic missiles. Component technology under development will reduce development risk for lightweight, high temperature erosion resistent nozzles. Risk reduction is being addressed at all levels of development of three-directional reinforced carbon-carbon composite material constructions for exit cones. Development of unique evaluation and inspection techniques through the development of nozzle component acceptance and rejection criteria is expected to lead to significant risk reduction. New and innovative nozzle designs are non-involutes and the payoffs expected are lower cost, reduced inprocess rejections, and higher reliability.

The Advanced Front-End Propulsion cluster provides payload propulsion technology for advanced strategic missile front-ends to enhance missile penetration/survivability with improved post boost propulsion and/or increased vehicle weapon delivery footprint.

The Ballistic Missile Propulsion Analysis cluster conducts analyses of future propulsion options for intercontinental ballistic missiles (ICBMs). The objective of this cluster is to quantify the advantages and disadvantages of different rocket propulsion options for ICBM propulsion in terms of payload, range, response time, etc. An outstanding example of this kind of analysis is the work recently done on the Small ICBM (SICBM) for the Ballistic Missile Office. During this effort, analysts investigated the SICBM mission and differing solid fuel and liquid fuel propulsion options for a volume and weight limited missile. Future analysis efforts will focus on advanced, high-performance propulsion systems for ICBMs. One promising area is nuclear propulsion. The usual product of an effort within this cluster is a study or report that is used to guide propulsion technology investment within the Air Force.

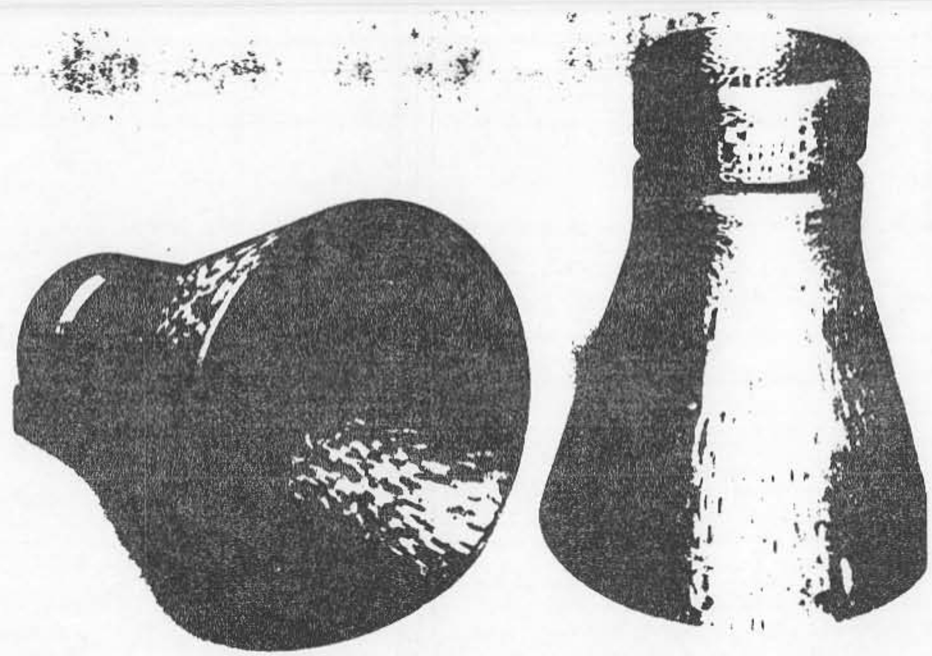
c. Payoffs

The Ballistic Missile Propulsion Technology thrust provides many significant missile system improvements. Increased service life, operational capabilities, and improved non-destructive motor evaluation are products of our Service Life cluster. Advanced component development will lead to an increased range or throw-weight capability using the Integrated Stage concept as compared to a stage using state-of-the-art technology. Nozzle and exit cone technology investment will lead to lower risk and lower weight nozzle systems. Development time for nozzles and exit cones will be reduced and system reliability will increase. Advanced front-end propulsion technology will reduce system weight, and increase reliability and footprint for post boost vehicles.

Figure 29 identifies the Ballistic Missile Propulsion thrust transition targets. Technical accomplishments in this thrust are used to improve the performance of numerous systems and to minimize operational failures. Air Force operational requirements can only be met if the systems perform as predicted. Improvements in the service life of solid propellant systems and the development of testing methods to accurately predict system readiness minimize operational failures. Minuteman, Peacekeeper, and Small ICBM have benefitted and will continue to benefit from the technical accomplishments in this thrust. The Advanced Strategic Missile Systems Office depends on the technical accomplishments in the Ballistic Missile Propulsion thrust to help meet future operational requirements and they assist AFRPL in integrating the technologies into systems.

Ballistic Missile Propulsion Nozzle and Exit Cone Technology....

- Nozzle Material Characterization
- Innovative Nozzle Design
- Nondestructive Evaluation
- Mechanics of Involute Failure



00215

FIGURE 28

Ballistic Missile Propulsion

Transition Targets....

- Systems
  - Minuteman Upgrade
  - Peacekeeper Block Change
  - Small ICBM
  - Advanced Strategic Missile System
- Logistics
  - Service Life
  - Nondestructive Evaluation

00207

FIGURE 29

d. Funding

The table in Figure 25 shows the total funds to be expended in the Ballistic Missile Propulsion Technology thrust from FY 85 through FY 87. The following is an identification of the Program Elements supplying funds to this thrust:

61101F - Laboratory Director's Independent Research Program
61102F - AFOSR Research
62102F - Materials
62302F - Rocket Propulsion
63302F - Space and Missile Rocket Propulsion
64312F - Peacekeeper (MX)
64609F - Logisitcs Technology for Weapons Systems

e. Future Plans

Work in the Ballistic Missile Propulsion thrust concentrates on two basic capabilities: to be able to accurately predict changes in the structural properties of ballistic missile motor propellants and components during deployment and long-term storage, and to develop propellant and component manufacturing technology to ensure ballistic missile motors will meet or exceed Air Force operational requirements. Future efforts will continue to develop these basic capabilities. Some of the major efforts AFRPL has planned in this thrust are identified in Figure 30.

Work is planned to determine the effects of manufacturing variables and humidity, from both inside the motor and from the environment, on structural and ballistic characteristics of high energy propellants. A motor analog will be developed to accurately simulate propellant/liner bonding characteristics in a full-scale motor.

Filament-wound insulators are simpler and less expensive to fabricate than existing insulators. This technology is being integated into the Small ICBM.

To ensure the development of a Fast Launch ICBM (FLICBM) propellant, a program is planned to study scale-up of a research propellant mix to a production propellant mix. The structural and ballistic characteristics of the propellant must meet or exceed FLICBM operational requirements.

In the area of Nozzle and Exit Cone Technology, much work is planned to determine how to properly characterize the numerous types of carbon-carbon weaves and how to build and test nozzle and exit cones constructed of these unique weaves.

An AFRPL Component Laboratory is being built to enable us to develop our own carbon-carbon and case fabrication capability. Some of the major goals of the laboratory are to develop non-proprietary processing techniques, characterize advanced fibers and resins, develop material inspection techniques, and establish nozzle and case failure criteria.

Ballistic Missile Propulsion

Future Plans

- Manufacturing Variables and Humidity Effects on High Energy Propellants
- Motor Analog Validation
- Full-Scale Filament-Wound Insulator
- Fast Launch ICBM Propellant Scale-Up
- Assess Characterization Techniques
- Innovative Nozzle Construction
- Component Lab Advancement

FIGURE 30

5. Multiple Application Rocket Propulsion Technology

This technical thrust is the germination bed of design and evaluation techniques that decrease development risks and life cycle costs, increase the design reliability of rocket propulsion systems, minimize the impact on the environment of rocket propellants and ingredients, and evaluate the feasibility of advanced concepts for rocket propulsion. This thrust is illustrated and summarized in Figures 31 through 35.

a. Objectives

The work in this thrust provides the general technology or "core technologies" that serve as building blocks to the other laboratory technical thrusts. The objectives of this thrust are summarized in Figure 31. Generally, the advances in this thrust tend to be incremental and provide a broad base of research and applied technology to yield information that contributes to the solution of existing problems and looks forward to step function improvements or even to breakthroughs. This thrust uses knowledge from the fundamental physical sciences to generate engineering problem solving tools. The work performed in this thrust will generate the information bank that new systems will draw upon as we attempt to solve the exploratory and advanced development problems. It is conceivable that one or more of these efforts could led to either a quantum jump in capability or a break-through that will radically change the direction of development of rocket propulsion systems. The application of two or more small technology advances can result in a large improvement in system capability.

Also, in this thrust, we are looking for less expensive ways to obtain design data. We use computers to provide accurate predictive performance and design data to eliminate the need for many large full-scale hardware tests. We must be able to predict how propellants, structures, and components will respond under various environmental conditions imposed by the ambient surroundings and the combustion thermal environment during rocket operation.

The propulsion implications in this thrust are driven by the fact that present chemical energy sources are approaching a practicable limit as seen in Figure 32. Future systems will require a higher energy density. Consequently, new energy sources must be found. Therefore, we must evaluate revolutionary, unique propulsion concepts. Weapon systems users must have fewer propulsion problems. We must learn to design it right the first time! This means we need better performance prediction tools. Future conventional propulsion systems project needs for increased performance. In the core technologies area, we strive to lower processing costs, develop advanced propellants and synthesize new ingredients to achieve higher delivered energy. Instances of combustion instability can cause performance loss, and in some cases, destruction of an entire motor or missile. We must be able to understand the combustion processes. We are looking for ways to improve the quality and reduce the cost of combustion stability measurements. Future missile systems need to have a longer service life capability. Presently, service life prediction is an art; not a science. We need to develop means to predict and assess motor structural integrity to eliminate the present costly approach of having to remove missiles from the field and physically take them apart to determine their acceptability.

5-5-15-1 D56

Multiple Applications Technology....

OBJECTIVES

- Foster & Establish Feasibility of Unique Propulsion Concepts
- Advance State-of-the-Art in Core Technologies Applicable to All Rockets

CLUSTERS

- Advanced Propulsion Concepts
- Propellant Fundamentals
- Improved Solid Propellants
- Combustion Technology
- Motor Structural Integrity
- Improved Propulsion Safety

FUNDING ($×MILLIONS):

PE	FY85	FY86	FY87
61101F	0.1	—	—
61102F	1.9	2.0	2.0
62302F	7.7	9.9	11.8
Other	1.7	0.6	0.5

PAYOFFS

- Revolutionary System Capability
- More Reliable & Maintainable
- Lower Initial & Replacement Costs
- 42% Reduction in Processing Costs
- Reduced Temperature Sensitivity (-) $\Delta \pi_k$ of 0.03 Equals (+) 1 sec of Isp

00268

FIGURE 31

Must We be Limited by Chemical Propulsion Barriers?....

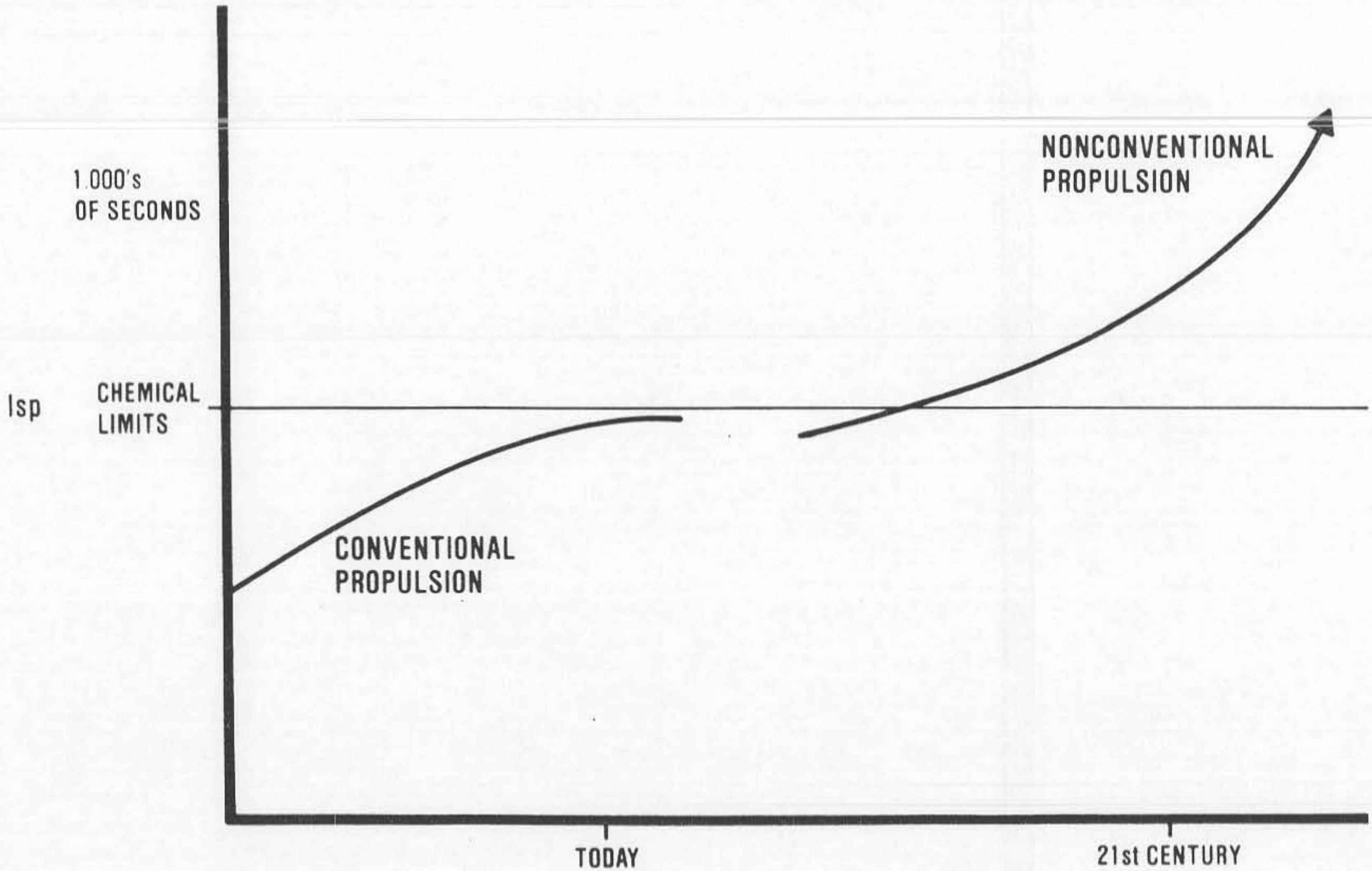


FIGURE 32

b. Clusters

The efforts in this thrust are grouped into clusters as shown in Figure 31. The Advanced Propulsion Concepts cluster looks at radically new propulsion concepts such as solar power, magnetoplasmadynamic (MPD), and novel launch techniques. Basic research in advanced energy generation and storage is continuing at a fundamental level. Better solid propellant processability, stability, lower ingredient and processing costs, and improved physical properties are the goals for the Propellant Fundamentals cluster. The Combustion cluster is chiefly concerned with improved combustion efficiency and stability for both solid and liquid rockets. The mechanism and kinetics of the combustion and internal flow process are examined and modeled; this provides methodology for improved performance designs. Using the historical shelf-life data from operational missile motors the Motor Structural Integrity cluster investigates methodology for longer life solid rocket motors. This includes the propellant, case, liner, insulation and the interfaces between these materials. The Improved Propulsion Safety cluster addresses the need for safe handling of propellant chemicals and associated rocket materials in the field. This demands an understanding of hazards, toxicity, and establishment of proper disposal procedures.

c. Payoffs

New, better, and cheaper ways to provide reliable rocket propulsion best describes the payoff of this thrust. The programs in this thrust provide the basic ground work from which our understanding of rocket propulsion evolves; these are our "core technologies." The understanding derived from this thrust allows us to investigate innovative propulsion concepts, to develop improved propellants for increased solid rocket performance, and to provide low risk, low cost propulsion concepts and approaches. Efforts are underway that promise to reduce propellant processing costs by 42 percent. Ballistic modification to reduce the propellant temperature sensitivity can provide the equivalent of several seconds of specific impulse when used to optimize rocket motor design parameters.

Figure 33 identifies the Multiple Applications Technology thrust transition targets. Transition to the applications thrusts is the significant output of technology from this thrust. We seek energetic, stable and safe propellants. The combustion process must be stable and efficient. Improved design tools are needed for structural and combustion analyses. Advanced concepts demonstrations are needed to provide the push to systems offices. The concepts are high risk, but have very high payoff potential. In a generic sense, all improvements must be made without compromising logistics requirements. We seek before the fact improvements and after the fact solutions.

d. Funding

The table in Figure 31 shows the funding we plan to apply to this thrust. The Program Element 61101F monies are from the Laboratory Director's Independent Research Fund. The 61102F monies are AFOSR research funds being applied to rocket propulsion goals. All of the exploratory development investigations are accomplished under Program Element 62302F, Project 5730.

e. Future Plans

Figure 34 identifies the FY 86 projects in this thrust. They are presented in the general order according to the cluster responsible for the work.

Multiple Applications Technology

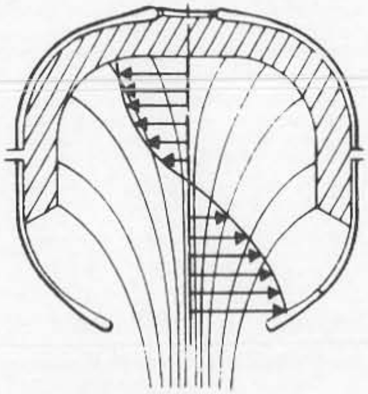
Transition Targets....

- Applications Thrusts
  - Energetic, Stable, Safe Propellants
  - Combustion Stability; High Efficiency
  - Improved Design Tools
- System Technology Pusher
  - Advanced Concepts Demonstration
  - High Risk - High Payoff
- Logistics R&D
  - Before the Fact Improvements
  - After the Fact Solutions

FIGURE 33

5-5-15-1 D71

Multiple Application Propulsion Technology FY86 Program....



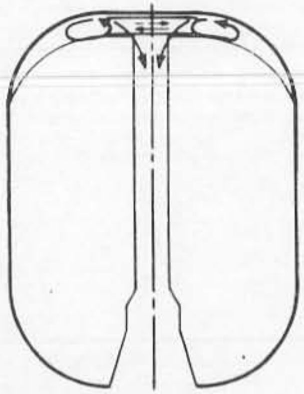
GPS (Star-48)

↓

Elastoid-Inertia Waves

↓

Coning Anomalies



Peacekeeper/Trident

↓

Buoyant, Swirling Head End Flow

↓

Head End Erosion

- Diffuser Investigation
- Metastable Helium
- Continuous Processing
- Thermoplastic Elastomers
- Velocity Coupling
- Analysis of Spinning Motors
- Head End Flow Effects
- Advanced Flowfield
- Temperature Sensitivity
- Nitramine Mechanisms
- High Expansion Boundary Layer
- Insuliner Technology Demo

00282

FIGURE 34

Adequate ground test facilities for electric propulsion are needed. Toward this end, the potential for using a diffuser to aid in the maintenance of a suitable vacuum for magnetoplasmadynamic (MPD) thruster testing will be investigated. Advanced nonconventional propulsion concepts such as excited state molecules will continue to be evaluated. Propellant development will be emphasizing potential means to reduce costs such as continuous processing and use of thermoplastic elastomers. Combustion efforts will continue to emphasize propellant temperature sensitivity technology, coupling of acoustic signals with the accelerating combustion gases, and three dimensional flow field phenomena especially in the motor head end area. Mechanisms of non-HCl producing oxidizer combustion will be investigated. High expansion ratio boundary layers will receive emphasis for certain liquid rocket engines. Demonstration of insuliner technology will be accomplished as well.

The anticipated FY 87-88 program emphasis is outlined in Figure 35. Electric propulsion thermal management will be investigated as will 100 KW Arcjets. Plasma propulsion and magnetic nozzle concepts will be evaluated. Analytical efforts will begin for nuclear fuel particle concepts and advanced orbit transfer vehicle (OTV) rocket engines. Future propellant emphasis will focus on GAP characterization, development of new polyisocyanates, high energy internal plasticizers, high energy zero/negative slope propellants, as well reduce cost processing. Combustion response function measurement using MHD concepts will be evaluated. Motor structural integrity will emphasize pressure cure technology, interface aging interactions and effects of nonhomogeneity in propellants properties.

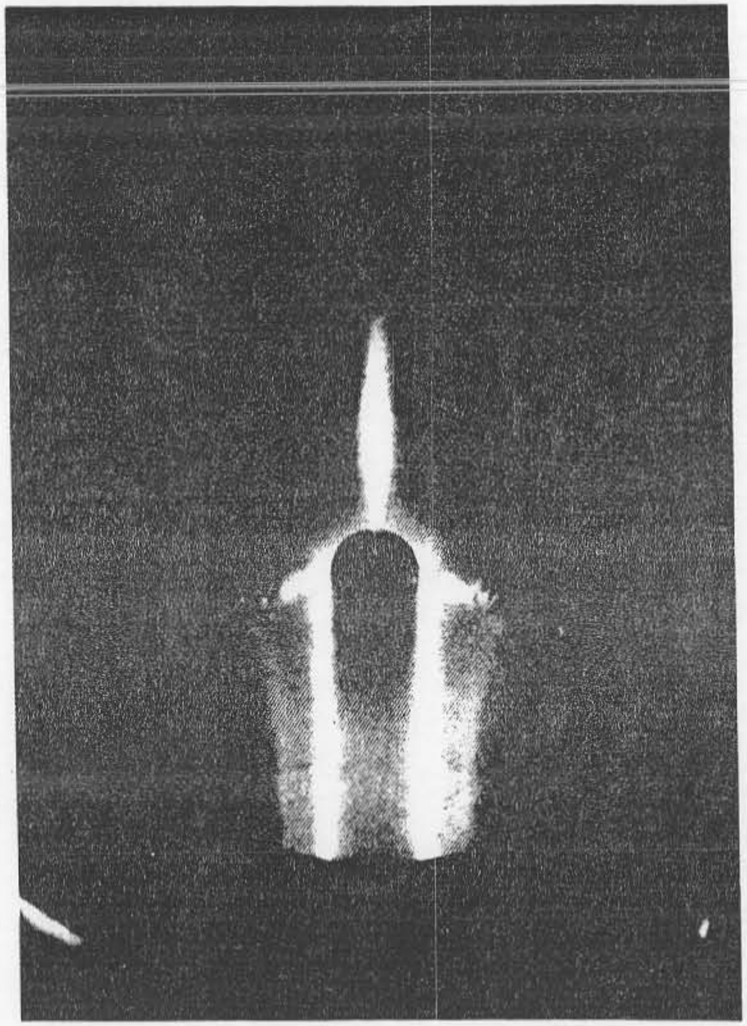
ORGANIZATION

AFRPL organizational chart as of 1 September 1985 is shown in Figure 36.

FACILITIES

AFRPL facilities are shown pictorially in Figure 37.

Multiple Application Propulsion Technology FY87-88 Program....



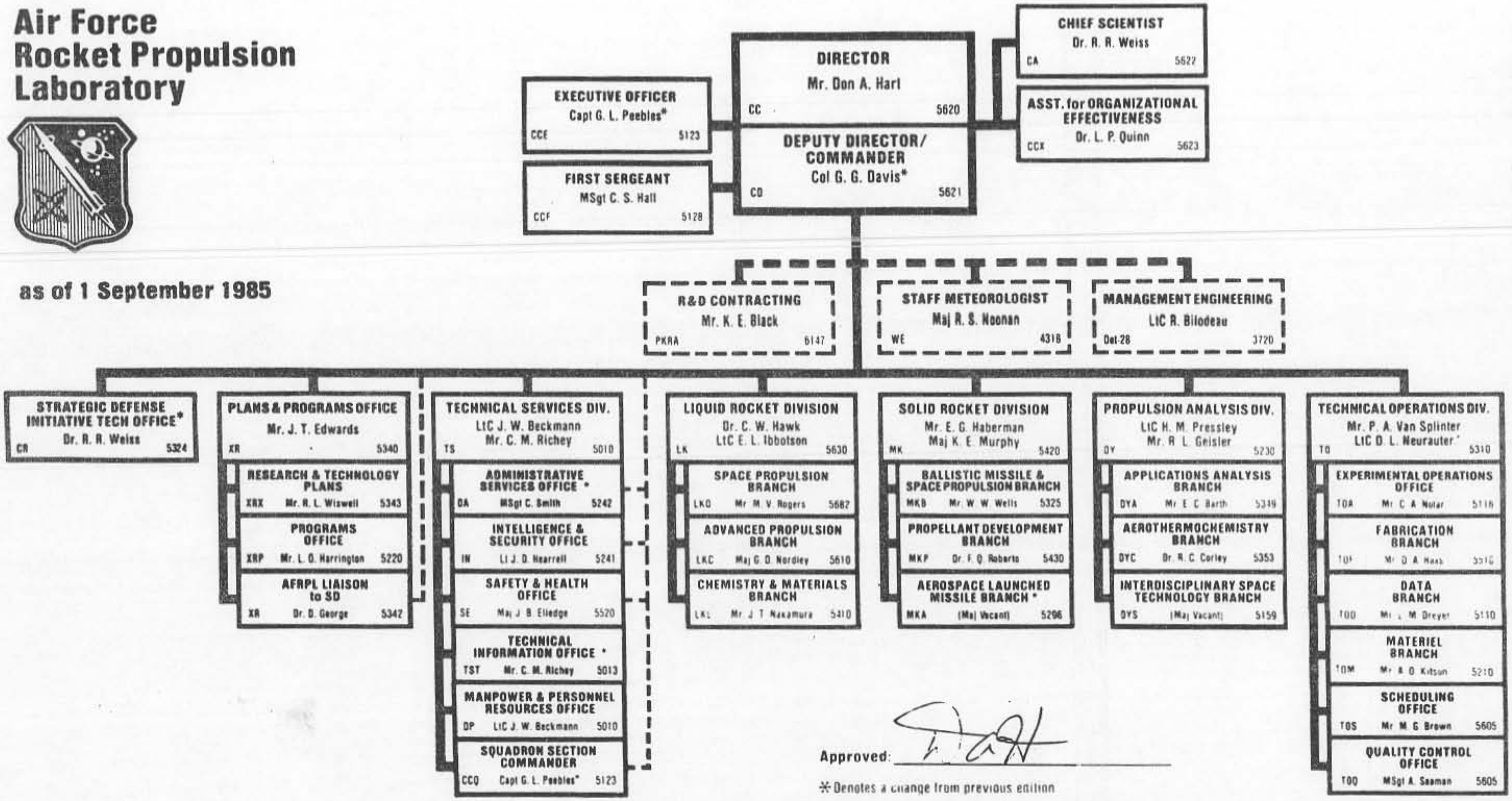
- EP Thermal Management
- 100 kw Arcjet
- Plasma Propulsion
- Magnetic Nozzles
- Nuclear Fuel Particle Analysis
- OTV Rocket Engine
- GAP Characterization
- New Polyisocyanates
- High Energy Internal Plasticizer
- High Energy Zero/Negative Slope Propulsion
- Reduced Cost Processing
- MHD Response Function Prototype
- Pressure Cure Technology
- Interface Aging Interactions
- Nonhomogeneity Effects

00281

FIGURE 35

Air Force Rocket Propulsion Laboratory

as of 1 September 1985



Approved: ____________

* Denotes a change from previous edition

EDWARDS AIR FORCE BASE, CA 93523
Autovon: 350-XXXX Commercial: (805) 277-XXXX

FIGURE 36

AIR FORCE ROCKET PROPULSION LABORATORY FACILITIES....

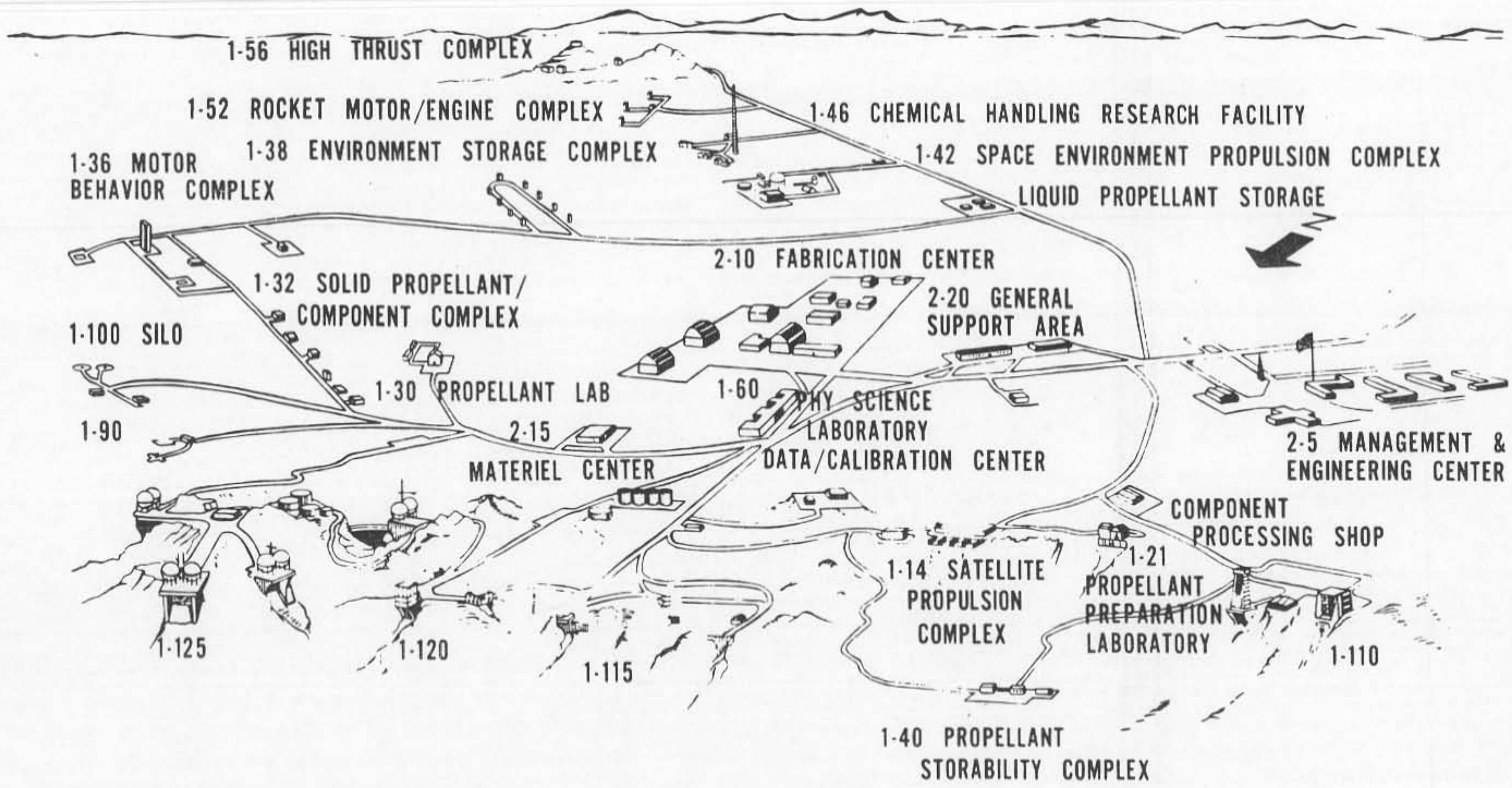


FIGURE 37

APPENDIX

FY 86 & 87 COMPETITIVE PROGRAM LISTING

Notes:

1. This list contains those programs we expect to award to industry competitively.

2. The program work units are organized by Technical Thrust.

3. While not a specific Technical Thrust, the programs in support of SDI are included.

4. This program list was prepared as a "slice in time" and is subject to changes.

5. The following definitions apply:

   6.3 - Program funded with PE 63302F funds

   PRDA - Program procured with the Program Research and Development Announcement method

   SBIR - Program funded through the Small Business Innovative Research program

FY 86 COMPETITIVE PROGRAMS

Thrust A - Ballistic Missile Propulsion Technology

1. Rational Bond Test Verification
2. High Rate, High Press Propellant for Strategic Missile
3. Hot Gase Chamber Bleed Valve for Integrated Stage
4. Advanced Integrated Stage Technology for Ballistic Missile (6.3)
5. Low Cost TVA System (PRDA)
6. NDE Data Application
7. Mech Properties of Rocket Nozzle Adhesives (SBIR)

Thrust B - Air-Launched Missile Propulsion Technology

1. High Pressure, Low Rate, Low Observable Propellant
2. Non-Symmetric Motor Case
3. High Performance/Low Observable Motor (6.3)
4. Parastic Ignition
5. Damage Assessment for Composite Case
6. Service Life Verification
7. Plume Radar Cross Section
8. Propulsion Application and Preliminary Analysis Code

Thrust C - Space Systems Propulsion Technology

1. Nozzleless Booster Hardware Demonstration
2. Self Actuating Variable Area Nozzle (PRDA)
3. Cryogenic Propellant Production
4. Large Low Cost Titanium Tanks
5. Flightweight XLR-132 Engine (6.3)
6. Integrated ACS Study
7. Compact Cryogenic Feed System Demonstration (6.3)
8. Low Thrust Cryogenic Engine (6.3)
9. Maneuvering Propulsion Study (PRDA)
10. Deployable Solar Concentrator Development
11. 30KW Arcjet Electronics
12. 3-D Plume Analysis
13. Fuel Vent Modelling
14. Advanced Propulsion for Rapid Response from Orbit (PRDA)
15. Orbital Resupply Vehicle Propulsion Study

Thrust D - Multiple Applications Propulsion Technology

1. Thermoplastic Elastomer for Solid Propellant (SBIR)
2. Thermoplastic Elastomer Development for Propellant Binders
3. Continuous Processing (PRDA)
4. Continuous Low Cost Processing (SBIR)
5. Non-Linear Constitutive Theory Transition
6. Stress Transducer Application
7. Insuliner Technology Demonstration
8. Handling of Damaged Solid Propellants
9. Advanced 30KW Class Arcjet
10. Advanced Space Propulsion Study
11. Boundary Layers (PRDA)
12. Temperature Sensitivity Verification
13. Nitramine Burn Rate Verification
14. Stability Design Methodology (PRDA)
15. System Analysis of Spinning Rocket Motors
16. Head End Flow Investigation
17. Advanced Flow Field Model
18. Velocity Coupling (PRDA)
19. Adaptive Feedback Control for Acoustic Cavity (SBIR)

Thrust E - Interdisciplinary Space Technology

1. Advanced Reaction Motor Technology
2. Have Dagger
3. MLI Thick Blanket Performance
4. Slew Actuator System Requirements Study
5. Deployment Dynamics Software Development
6. Space Model and Control (SBIR)
7. Moving Belt Radiator for Space
8. Liquid Droplet Radiator Feasibility Exp
9. Contamination Data Base Management
10. Contamination Monitor System Definition Study

Strategic Defense Initiative

1. Oxygen/HC Thrust Chamber
2. Oxygen/HC Turbomachinery
3. Fluid Management Experiment
4. Low Cost Solid Propulsion Study

FY 87 NEW COMPETITIVE PROGRAMS

Thrust A - Ballistic Missile Propulsion Technology

1. Probabilistic Fracture of Brittle Materials
2. Full-Scale Shingle Lap Extendible Exit Cone
3. Innovative Nozzle Construction
4. Assessment of Characterization Techniques
5. Advanced Front-end Systems Demonstration
6. Ballistic Missile Manufacturing Variability
7. Humidity and High Energy Propellants
8. Structural/Ballistic Interaction
9. Strain Augmented Ballistics

Thrust B - Air-Launched Missile Propulsion Technology

1. 1.3 Minimum Smoke Propellant Demonstration
2. Solid Fueled Ramjet Booster
3. Laser Burnrate Demonstration
4. Ultra Long Motor Case
5. High Pressure Nozzle
6. Composite Attachment Demonstration
7. Low Shock Consumable Igniter
8. Cumulative Damage for High Strain Motors

Thrust C - Space Systems Propulsion Technology

1. CVD Coating Technology Demonstration
2. XLR-132 Injector Technology
3. Reusable XLR-132 Technology
4. Integrated Storable ACS Demo
5. Altitude Compensating Nozzle
6. Reusable Propellant Tank
7. Test Bed Engine Definition
8. Advanced Engine Conditioning Monitoring
9. Combined Cycle Engine Components
10. Advanced Turbine Materials
11. Baseline 30KW Arcjet
12. Sensor Demonstration Tests
13. Dust Entrainment Measurements
14. Plume Signature Model Verification

Thrust D - Multiple Applications Propulsion Technology

1. 100KW Arcjet
2. Magnetoplasmadynamic Thermal Management
3. Advanced Electric ACS
4. Antimatter Combustion
5. Magnetic Nozzles
6. Orbit Transfer Nuclear Rocket Engine Technology
7. Electric Propulsion Space Test Study
8. GAP Characterization
9. New Polyisocyanates
10. Reduced Cost Processing Techniques
11. Propellant/Case Interface Aging
12. Pressure Cure Technology
13. Nonhomogeneity Effects
14. Space Operations Hazards Study
15. Improved Hazard Test Methods
16. Fixed Bed Reactor Safety Study
17. High Energy Internal Plasticizer
18. High Energy Zero/Negative Slope Propellant
19. MHD Response Function Prototype

Thrust E - Interdisciplinary Space Technology

1. Space Heat Exchanger Ground Demonstration
2. Accommodation/Sticking Coefficient Definition
3. Contamination Design Criteria
4. Thermodynamic Vent Components Demonstration
5. Two Axis Large Angle Slew Experiment
6. Electric Thruster Diagnostics Demonstration

Space Defense Initiative

Unknown at this time