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National Remote Computational Flight Research Facility

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National Remote Computational Flight Research Facility

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NOMENCLATURE

AAA	anti-aircraft artillery
ACMR	air combat maneuvering range
AI	artificial intelligence
ARIA	advanced range instrumentation aircraft
BAI	battlefield air interdiction
BVR	beyond visual range
C^3	command, control, and communication
CAS	close air support
DARPA	defense advanced research projects agency
DCA	defensive counter air
DFRF	Dryden Flight Research Facility
DOD	Department of Defense
ECM	electronic counter measures
FEBA	forward edge of battle area
FORM	formation flying
FRS	flight replacement squadron
GPS	global positioning system
IADS	integrated air defense system
InMASS	integrated multiple aircraft surface strike
INS	inertial navigation system
IRMD	infrared missile defense
JTIDS	joint tactical integrated data system
MEZ	missile engagement zone
Minis	mini computers
MRGU	mobile remote ground unit
MvN	"M" versus "N" or "M" on "N" means M aircraft in
MonN	air combat against N aircraft
NASP	National Aerospace Plane
NRCFRF	National Remote Computational Flight Research Facility
OCA	offensive counter air
PVI	private vehicle interface
RAP	remote airborne platform
R&T	research and technology
RAV	remotely augmented vehicle
RHAW	radar homing and warning
RMD	radar missile defense
ROE	rules of engagement
RTU	replacement training unit
RW	robotic wingman
SAM	surface-to-air missile
SATE	situation assessment and threat evaluation
SD	senor detection
SEAD	suppression of energy air defense
TAF	tactical air force
TDRS	tracking of data relay satellite
TDRSS	tracking of data relay satellite system
TI	tactical intercept
TR	threat reaction
VIU	vehicle interface unit

1.0 INTRODUCTION

Manned aeronautical vehicles and associated operations are increasingly dependent upon information gathering and processing technology. The need for improved performance and effectiveness, enhanced safety, expanded options, and novel mission, procedures and systems continue to grow. The era of the pilot-executive/strategist assisted by an electronic crew furnishing well digested inputs, advice and counsel; and executing, under supervision, plans which account for the foreseeable future, is nearly at hand. The critical issue for the realization of this era is integration not only of the man and the machine, but of the man and the total environment comprising tasks, immediate externals, forecasts, competitive and cooperative elements in the environment, and the vehicle. All of the system elements except the man can be fundamentally changed -- but the human's capacities within the changed flight environments potentially established by all the new system possibilities remain central.

To accomplish such expanded manned vehicle systems integration possibilities will require a special kind of research aimed at matching the system and operations to the human which far exceed previous efforts in kind and in degree. For the really novel and critical new operational and mission possibilities, the pilot will not only be a controller (at times at least), communicator, systems and crew supervisor, etc.; but will take on roles as strategic and tactical flight manager, innovator, diagnostician, redundancy manager/executor, etc. The new systems will aid the pilot, augment the pilot, advise/guide the pilot and at times perform totally automatic maneuvers. But, inevitably, the new systems will also further stress and stretch the pilot's capabilities and direct his actions into different streams. To live up to the promise of the new information gathering and processing potential, the pilot must be enormously broadened in scope and must operate a parallel processing mode. The effects of the new system possibilities will be measured not only by their possible improvements, enhancements and capabilities; but, most importantly, by their symbiotic and synergistic impact on the pilot -- who must live with and make the whole thing work.

An enormous amount of highly imaginative research and experimentation will be required to turn the promises of the new information technologies into concrete aeronautical system advances. A great deal of the early research can be done in ground-based simulators. But it is axiomatic that when dealing with the flight environment that flight demonstrations are essential. It is our belief that when novel operations and missions are considered in company with electronic replacements of crew functions, that the simulations needed are best developed with more, rather than less, flight research. This has been demonstrated again and again in the past, ranging from the first experiments on blind landing to modern day experiments in tactical operations of fighters, attack helicopters, etc. These are all in flight, not in a simulator, because the true environments cannot be adequately simulated. With the new technology, the "environments" themselves, will be variables, and some may not even be understood until the flight situation is encountered in its totality.

The NASA Ames/Dryden Flight Research Facility has devised a unique flight testing capability called the Remotely Augmented Vehicle (RAV) in combination withthe Western Aeronautical Test Range, that possibly could be expanded to provide an extraordinary new research and development capability for the nation. The idea is to provide massive computational power in a ground based facility that is linked to one or more aircraft to investigate new systems concepts that require extensive computational power in the real flight environment years before flight qualified computers are available. Even new computer architectures required for special processing, such as real time expert systems, could be tested and evaluated in flight experiments using experimental hardware on the ground, years before flight qualified versions are developed. The realistic flight environment is particularly important in cases where the technology is pushing for maximum performance from the combination of crew, vehicle, and highly integrated systems. With a remote computational flight research facility, the researcher would not be forced to accept the limitations of the ground based simulation in vision and motion systems or the ability to provide realistic mission and task related stress levels. The overall effect and benefit of such a facility would be to greatly accelerate the development and evaluation of computer-based aircraft systems technologies.

The basic concept is depicted in Figure 1. In addition to the massive computational power, there would be advanced pilot-vehicle interface systems in the cockpits of the test aircraft. Flexibility would be build into these systems so that the information content and format are programmable. The system should be capable of providing computer generated imagery in the cockpit displays which is produced, at least in part, within the ground based computers. The aircraft would be provided with standard interface units that contain the data links and other modules including an airborne processor and data systems. The concept could also support flight testing over an extended range as shown in Figure 2. Local operations could involve one aircraft or multiple aircraft internetted together by air-to-air data links. For example, remote mobile operations could be performed at special test ranges such as the helicopter range at Fort Hunter-Leggett. Support could be provided to transatmospheric vehicles such as the National Aerospace Plane (NASP) through a relay satellite.

This study investigated the feasibility of a national facility to provide extensive remote computation power to support flight research and testing. A wide range of programs and technology drivers was reviewed to determine which ones could potentially benefit from use of such a capability. The Robotic Wingman (RW) was identified by NASA as one such and potentially one of the first to use this capability to a significant degree.

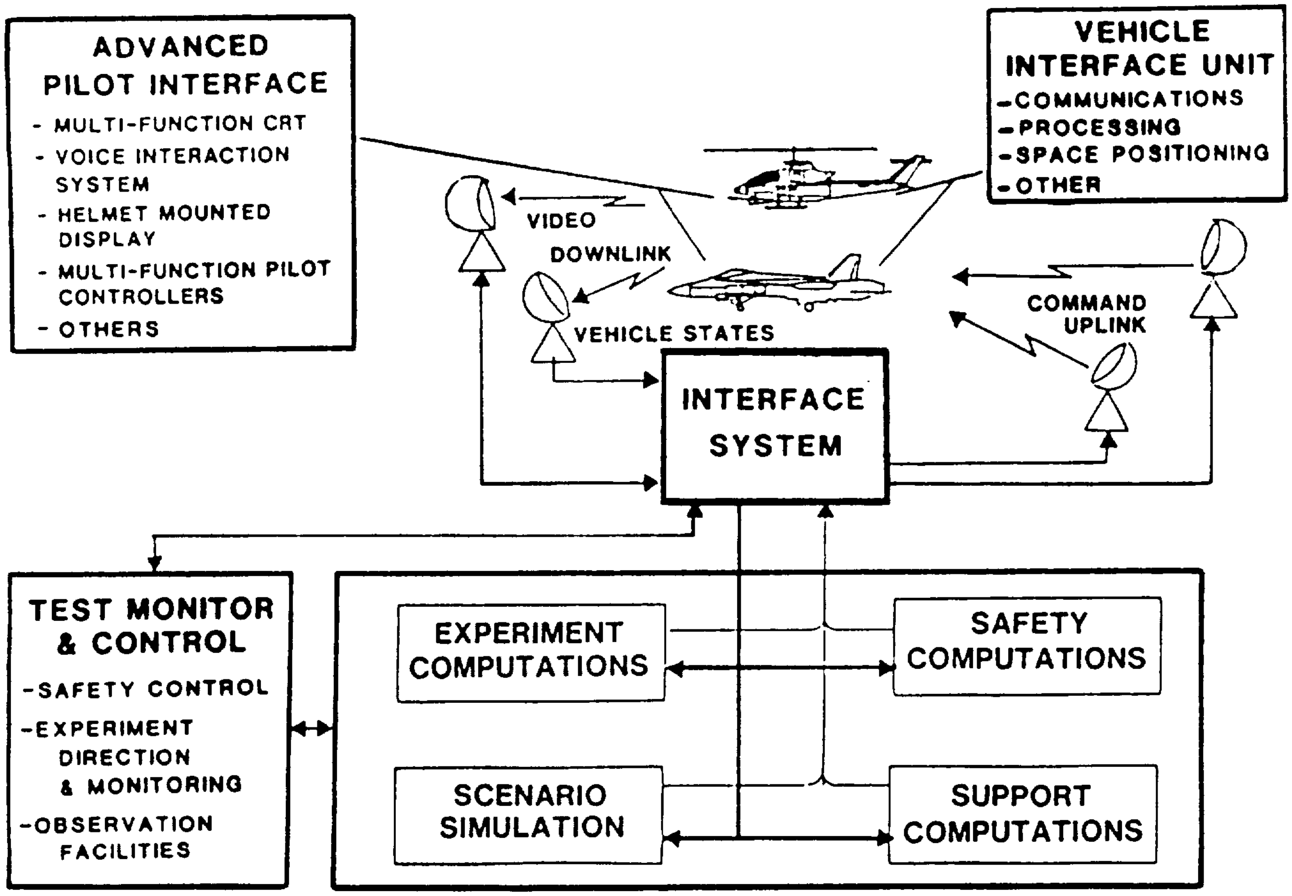

FIGURE 1. REMOTE COMPUTATIONAL FLIGHT RESEARCH FACILITY CONCEPT

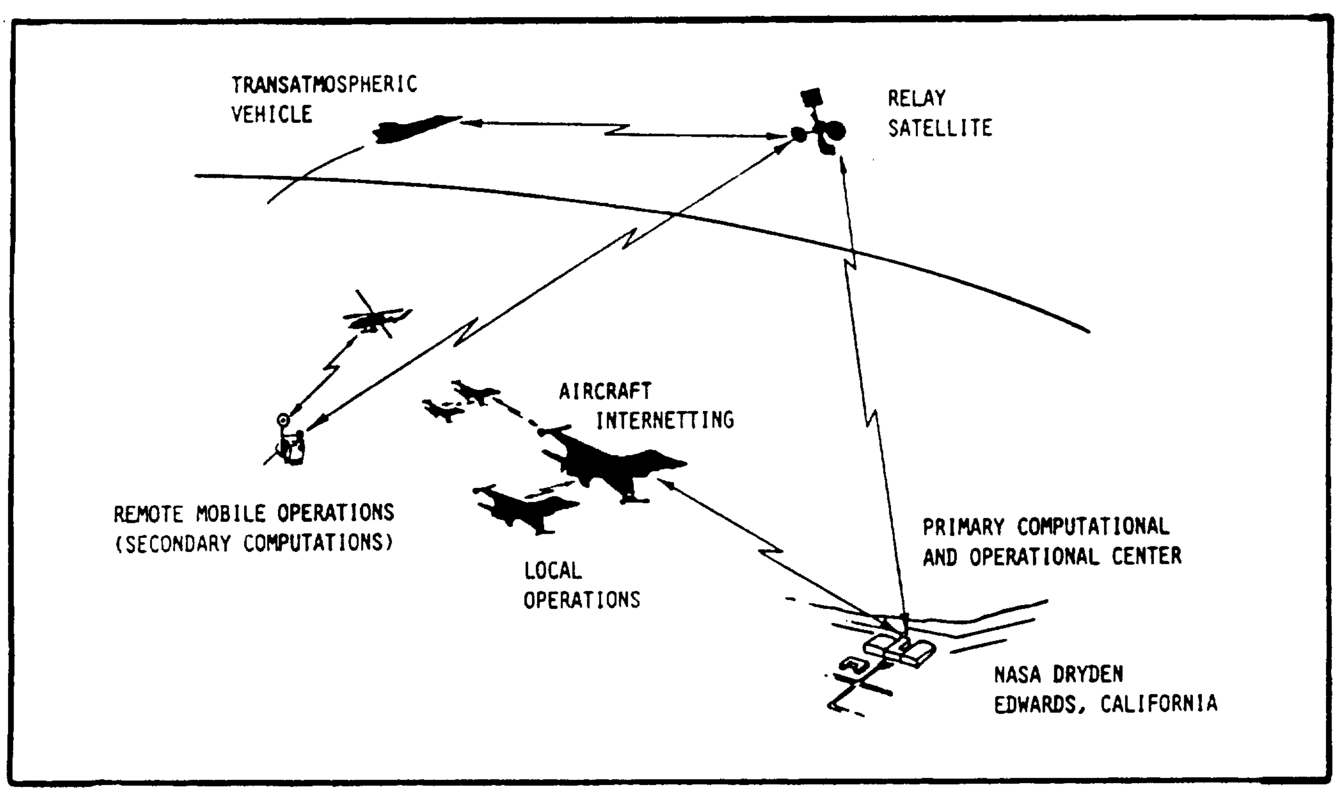

FIGURE 2. NRCFRF EXTENDED RANGE CONCEPT

Therefore, a more in depth investigation was conducted into an RW flight demonstration example.

Important parts of the study and overall justification are the test range and facility considerations. The terms "test range" and "facility" are used here in a very broad sense to include not only the remote computational capability but also special aircraft instrumentation and data-link pods; mobile and remote site operations; special airborne displays; threat modeling and simulation; special terrain courses; special ground support equipment; and space positioning and tracking.

The NASA Ames Western Aeronautical Test Range (WATR) current and planned capabilities combined with the flight test facilities of the DFRF provide the necessary core to support the proposed NRCFRF. Some unique, new capabilities will be required. Thus a very broad look at the test range and facility requirements is necessary to accomplish the objectives. For example, there are several DOD aircraft test ranges that have capabilities somewhat similar to those suggested for NRCFRF. It is necessary to understand these capabilities, the purposes of the various test ranges, and the potential relationship of these ranges to the proposed NRCFRF. In the long term, where feasible and appropriate, the NRCFRF might serve a variety of locations with varying degrees of capability. The intent could be for the NRCFRF to be a national facility providing the capability where it was needed to the maximum degree possible.

The study task was divided into three parts:

Part I - Research and Technology Requirements
Part II - Test Range and Facility Considerations
Part III - Robotic Wingman Scenario Definition.

The first part of the study was devoted to identifying the most important research and technology issues of future high performance aircraft and rotorcraft that require testing in a realistic operational flight environment and that would benefit from a remote computational capability. The requirements of relatively near-term programs such as HIDEC, and Aircraft Automation Program were considered as well as longer range programs such as a Transatmospheric Experimental Vehicle program. Research and advanced development were emphasized including proof- of-concept demonstrations and validations as well as potential uses of a remote computational facility in direct support of flight testing in areas of safety and efficiency.

Part II involved the identification of potential facility concepts and test range capabilities required for a NRCFRF. This included reviewing existing U.S. aircraft test ranges and establishing the relative uniqueness of the proposed NRCFRF.

The third element of the study developed flight demonstration scenarios for the potential Robotic Wingman (RW) program with particular emphasis on a near-term demonstration. It included the establishment of appropriate future operational tactical scenarios in which the RW concept would be employed.

2.0 OBJECTIVES AND SCOPE

The overall objective of the study was to examine the feasibility of establishing a National Remote Computational Flight Research Facility (NRCFRF) providing, as a unique central feature, a massive and varied computational capability on the ground that can be linked to one or many aircraft simultaneously to operate like embedded airborne systems.

The specific objectives and scope of the three parts of the study were:

Part I - Research and Technology Requirements

Objectives

Develop the research and technology (R&T) requirements and justification for a NRCFRF.

Define the necessary flight test environment to accomplish the R&T.

Develop the justification for the flight research and testing.

Scope

Important technology drivers for future high performance aircraft and rotorcraft were to be identified. Existing, planned and potential future R&D programs that might benefit from remote computation were to be considered. At least two specific flight experiment examples were to be defined to illustrate the remote computational support concept to justify the flight testing.

Part II - Test Range and Facility Considerations

Objectives

Define the test range and facility capabilities required to accomplish the R&T requirements for NRCFRF developed in Part I.

Identify the uniqueness of NRCFRF relative to other US aircraft test ranges.

Scope

The current and planned capabilities of the Western Aeronautical Test Range (WATR) were considered the baseline for this effort. The test range and facility considerations were included in: the remote computational capability; data communication links; space positioning; test monitoring and control; aircraft instrumentation and interface functions; and, pilot vehicle interface functions. The facilities and capabilities of other existing US aircraft test ranges were to be reviewed and assessed relative to compatibility with and uniqueness from NRCFRF.

Part III - Robotic Wingman Scenario Definition

Objectives

Develop meaningful test demonstration scenarios for the RW program.

Establish operational tactical scenario(s) for the RW concept to show credibility of the flight demonstration scenarios.

Scope

This task was to start with today's operational wingmen and extrapolate to what the operational employment might be for an RW. After defining the hypothesized operational scenarios, a subset was to be identified that could be reasonably demonstrated using the NRCFRF in the near-term (by 1990) and the far-term (by 1995).

3.0 RESEARCH AND TECHNOLOGY REQUIREMENTS

3.1 Research and Technology Drivers

The task of identifying the most important R&T drivers was divided into four categories: (1) advanced flight systems concepts; (2) crew-vehicle systems integration; (3) experimental and/or advanced aircraft testing; and, (4) flight testing environment. A number of potential programs or opportunities in each area are discussed and the related computational drivers are identified in the following sections.

3.1.1 Advanced Flight Systems

Under the advanced flight systems category are those systems which require rather extensive computation in embedded flight computers or processors. This category is an extension of the type of systems testing that has typically been done in the existing RAV facility at DFRF, e.g., flight control laws implemented in the RAV ground computers and data linked to the F-8 Digital Fly-By-Wire manned aircraft.

The technology that first comes to mind which could benefit from the remote computational approach is automation, particularly, artificial intelligence. They typically require extensive computational power, well beyond that available in flight qualified computers. Four specific programs identified are: the Robotic Wingman (RW); Pilot's Associate (PA); Automated Nap-of-the-Earth (NOE); and, Autonomous Air Vehicle Avionics Suite (AAVAS). Although the objectives and specific technology sets in each program are different, they involve one or more of the following: multiple real-time expert systems; real-time mission planning or re-planning; advanced cockpit voice actuation vision system concept; image understanding and/or data fusion. All of these require extensive computation which could be demonstrated remotely with only the pilot vehicle interface and/or sensor suite onboard the test aircraft.

Robotic Wingman

The operational concept of an RW is that it could be a specially designed, high performance robotic aircraft and weapons systems platform that operates in conjunction with a lead aircraft much like current manned wingmen. It would require a high level of machine intelligence, certainly much higher than has been demonstrated to date. It supports the tactical decisions of the flight lead and performs certain tasks autonomously at the lead's direction. This is much more effective in a dynamic tactical situation than a robotic aircraft by itself, as some have suggested, since it retains the critical element of adaptable human intelligence in situ for the tactical decision making and uses the robotic aircraft to carry out commands. The RW could be build to have an enormous maneuvering performance advantage over manned aircraft. For example, it could pull ± 20 g's in normal acceleration and ± 5 g's in lateral acceleration. Such performance would not only be a tremendous advantage in air-to-air combat, but also in out-maneuvering existing missiles in defensive actions. The RW would be basically designed to have low observables, at least as low as the flight lead, but could also have radiators that could be turned of or off to act as a decoy, if necessary. As a last resort, the RW could even sacrifice itself to save the lead. Overall, it could increase the total fire power and, hence, leathality and put fewer pilots at risk. Fewer pilots would reduce support requirements.

The lead would give high level voice commands to the RW and the RW would transmit critical information back to the lead via synthesized voice and/or data to a cockpit display. Of course, the communications link would have to be secure. Such data links exist, for example, SPARTA's 60 GHz internetting link. The data link would also transfer vehicle state vectors and certain discretes. The basic system architecture consists of a suite of cooperative hierarchical expert systems (smart voice interface, heuristic controller, situation assessment, target recognition, and vehicle and weapons management and control) operating in real-time to perform wingman functions. An advanced sensor suite is also required on the RW.

The smart voice interface would have to interpret the lead's voice transmissions as information for the knowledge base, commands or other information through interactions with the heuristic controller. Onboard sensors information and knowledge base would be used in the target recognition system to identify and classify the threat. The tactical situation would be assessed by another expert system using information from the target recognition system and knowledge base. The heuristic controller determines what information needs to go where and what actions should be taken. If the action is to maneuver and/or deploy weapons, the vehicle and weapons controller would determine the appropriate maneuvers and weapons deployment. This is a rather simple description and example of what would be a very complex set of activities.

The key technologies required for an RW could be evaluated very effectively using NRCFRF. The real-time machine intelligence integrated with vehicle control is the unique enabling technology not being addressed by any other programs. The only true evaluation of RW performance is by the flight lead assessment which must be made in flight. Acceptance of the RW concept by the operational community is highly dependent on how the flight lead evaluates the RW performance. The technology test flights can be done with a safety pilot onboard the RW test airplane who would take over control if necessary. All the coordinated real-time expert systems and control algorithms would be implemented on the ground-based computers and the control commands data-linked to the RW test airplane.

When the automatic threat identification and classification technology, including multi-spectral sensor-suite and intelligence, are sufficiently developed under other DOD programs it would be desirable to incorporate them into an RW flight test program. Once the total RW technology set is adequately proven, one might want to demonstrate an unmanned RW using NRCFRF.

The RW concept is potentially one of the first to be demonstrated via the remote computational approach. It is treated more extensively in Part III (Volumes IV and V) of this report.

Pilot's Associate

A Pilot's Associate (PA) is an artificial intelligence-based electronic crewmember which provides high level information to the pilot and off-loads the pilot in critical high work-load situations. It contains several knowledge bases with stored information on such items as the aircraft system (i.e., performance characteristics, stability and control, weapons and ballistics, emergency procedures, etc.), mission related background (i.e., tactics, friendly forces information/identification, threat information/identification, etc.), and mission peculiar information (i.e., terrain data, navigation aides, communications, order of battle, etc.). An integrated processing and interpretation system is provided to perform such functions as sensor data fusion, threat interpretation/warning avoidance, knowledge base update, pilot information monitor, pilot command interpretation, system configuration status/monitor, navigation monitor/manager, etc. An intelligent pilot interface provides the capability for information exchange.

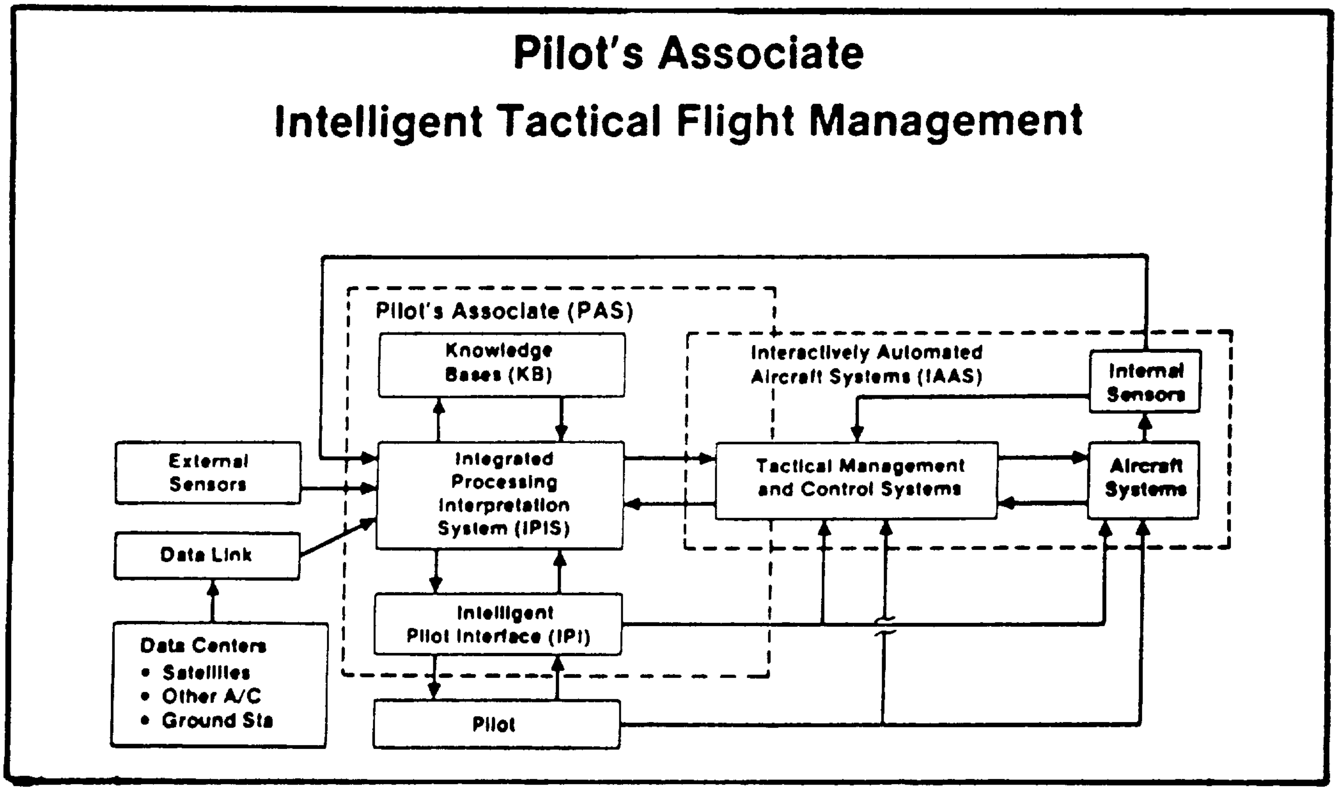

FIGURE 3. CANDIDATE ADVANCED FLIGHT SYSTEM CONCEPT FOR NRCFRF DEMONSTRATION

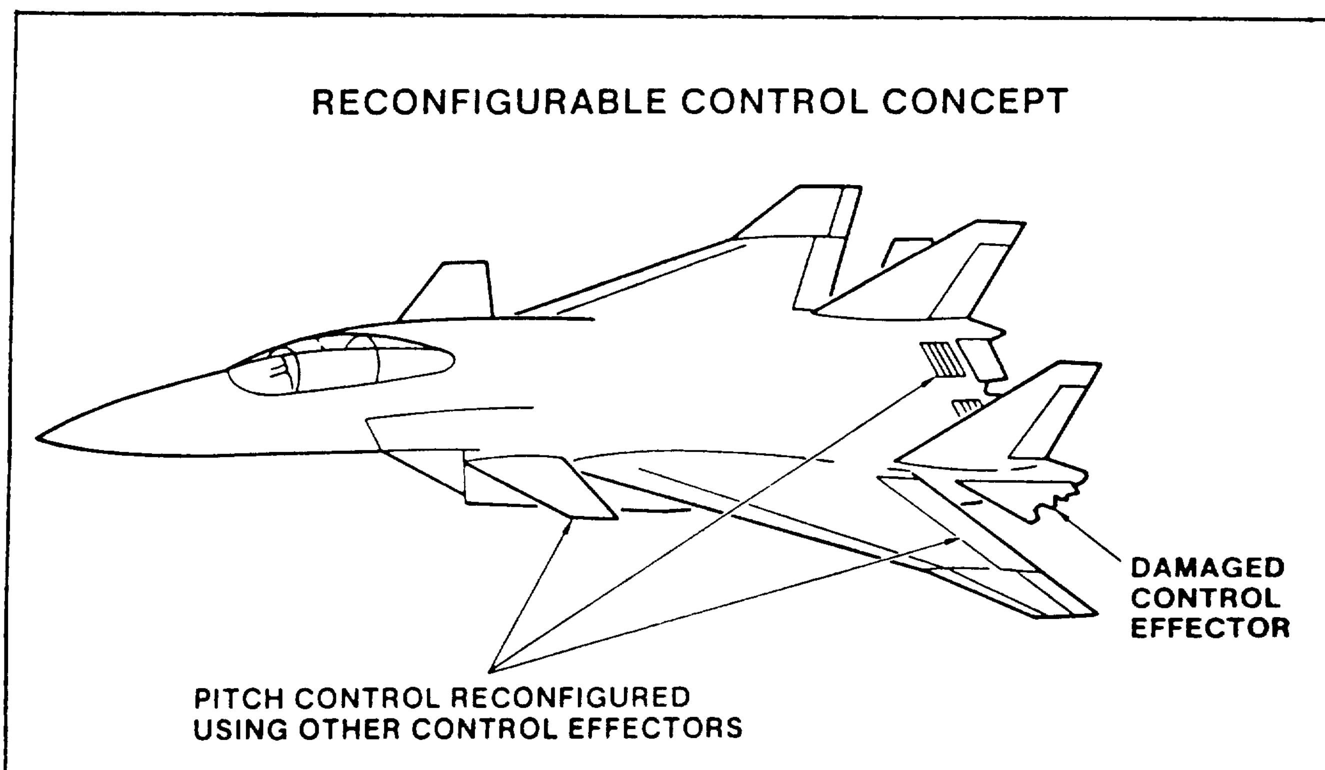

FIGURE 4. CANDIDATE ADVANCED FLIGHT SYSTEM CONCEPT FOR NRCFRF DEMONSTRATION

Coupled with an interactively automated aircraft system as shown in Figure 3, the PA system can integrate external/internal sensor information to conduct navigation tasks, and provide threat, target and assessment information. It can provide and monitor external communications and manage the cockpit by configuring displays and controllers. At the pilot's discretion, it can perform automatic system management and control such as manage support systems; generate, display, and control flight path trajectories; and, perform flight planning functions.

The current DARPA/Air Force PA program only plans to demonstrate the technology on manned mission simulation. Major elements of the PA program could be evaluated and/or demonstrated in the actual flight environment using NRCFRF.

Automated Nap-of-the-Earth

The NRCFRF would be ideal for supporting the flight demonstration portion of the NASA/ Army Automated NOE program in the mid- and far-term phases. With appropriate video and other imaging sensors onboard a test helicopter and a high data rate link to the ground station, advanced algorithms could be programmed on powerful ground computers. The resulting pilot displays and/or commands would be data linked back to the helicopter. Much more extensive algorithmic and logic processing could be implemented for the Automated NOE flight demonstration via NRCFRF than could be accomplished with onboard computers in the same time frame.

Autonomous Air Vehicle Avionics Suite

The Autonomous Air Vehicle Avionics Suite/Intelligent Munitions (AAVAS/IM) program is a DARPA/Army program to develop and demonstrate the software required for an advanced avionics suite needed for a fully autonomous air vehicle capable of dispensing intelligent munitions in high threat areas. The program assumes state-of-the-art sensors, guidance and control systems, and warheads. The software to be developed is to be capable of: sensor management; sensor data interpretation; target classification; target selection; attack decision; weapon initialization; weapon guidance; and, damage assessment. The current program plans a laboratory demonstration. The NRCFRF could be used to evaluate the software using actual flight sensors.

Reconfigurable Controls

A second type of advanced systems concept that could be benefited by remote computation is reconfigurable controls. With the emergence of powerful computational capabilities in future aircraft, the potential exists to effectively mitigate failures in the aircraft by system reconfiguration. In the example illustrated in Figure 4, the effects of a damaged tail section effecting pitch control can be minimized by redistribution of forces and moments using other control surfaces such as horizontal canards. Considerable research and flight demonstration/evaluations are necessary to realize the potential and NASA's facilities would be clearly suited to such research activities.

Highly Integrated Digital Electronic Control

NASA's HIDEC program is exploring engine and aircraft performance improvements through the use of more available information about an aircraft's state. The heart of the system is the replacement of hydromechanical engine controls with an electronic system which can handle the growing number of control and sensor outputs required for complex engines. Conventionally, engine fan and compressor stall margins are kept unnecessarily high at certain flight conditions to provide adequate margins at more critical conditions. These and other preset margins sacrifice engine performance. HIDEC enables these stall margins to be reduced and adjusted to the flight conditions resulting in thrust and fuel efficiency or using the extra power available to improve performance. The developments in this program have provided an excellent base for integrated controls research including the application of expert systems. The NRCFRF would provide a much more extensive computational capability for evaluating these concepts in flight.

Supercockpit

The USAF Crew Systems Development Roadmap, also referred to as the "Supercockpit" program, will entail the development of three separate increasingly sophisticated cockpit automation and display concepts. The Supercockpits will feature three-dimensional sound and visual display, voice and vision activation systems, rapid reconfiguration of cockpit controls and displays, and pilot state monitoring. The first cockpit, expected to be ready for full-scale development in 1990, would combine aircraft state, systems status, navigation, threat warning, communication, sensor and data link (JTIDS) inputs on a helmet-mounted display that would be used for sensor and weapon aiming, electronic warfare responses and other applications. The second cockpit, to be ready for full-scale development in 1992, adds a terrain data base to other inputs and also introduces a speech synthesizer, three-dimension sound generator, and voice controller to supplement helmet-mounted visual displays an controls. The final version (shown in the figure) is expected to be ready for full-scale development in 1994 and will incorporate a pilot state monitoring system with previously integrated elements of the cockpit, and it could use a large, non-helmet-mounted transparency for displays. These cockpit concepts are to be ground-tested over the next 10 years, and are expected to lead to technology ready for incorporation in operational aircraft around 1996.

The three different levels of cockpit sophistication would be ideally suited for evaluation and/or demonstration using the NRCFRF. Most of the hardware already exists or is in advanced development stages. The long-term development items relate to the airborne computers and software (e.g., virtual world generator, pilot-intent interference engine, knowledge base, terrain data base, etc.).

Internetting

Aircraft internetting refers to multiple aircraft operating as a single unit. The NRCFRF would be ideal to evaluate such concepts by serving as an emulator for various application computations. The internetted fighter concept called InMASS uses a tightly netted group of aircraft to attack ground targets. The group, some of which can be unmanned, operates like a distributed processing system and uses shared sensor data to increase the effectiveness. For example, one aircraft's radar could be locked onto a specific target while another's could be scanning for surveillance and yet the information from both radars could be made available to all aircraft via internetting. The concept which involves considerable airborne computing capability, could use a NRCFRF for evaluation of the survivability and strike effectiveness aspects against simulated defensive systems.

Synthetic Aperture Radar

Technology improvements for conformal antenna synthetic aperture radars (SAR) involve processing methods and computational techniques to compensate for spatial deformation. The NRCFRF would provide an excellent test bed for evaluating such technology.

System Monitoring and Maintenance

System monitoring and maintenance techniques are becoming increasingly important as systems become more complex, expensive and functionally critical. The quality of failure prediction methods and expert systems for "health" monitoring relates to the computational sophistication used. The advance of this technology requires considerable testing in the "real-world" environment which the NRCFRF could satisfy.

Integrated Controls

Controls integration offers significant improvements in system performance and efficiency. Given sufficient computer power for example, system models could be incorporated in the software design for real-time comparison and analysis of both individual systems and the intersystem effects. With this information, changes in flight parameters can be made depending on flight conditions. Such techniques are computationally intensive and require considerable real-time test and evaluation.

3.1.2 Crew-Vehicle Systems Integration Issues

Crew-vehicle systems integration issues are among the most important to research in the most realistic flight environment and most likely to benefit from NRCFRF capabilities. As was discussed in the opening of the introduction, the critical issue for realization of the emerging era of highly integrated systems is not only the functional integration of systems and the crew, but of the crew and the total environment comprising tasks, immediate externals, forecasts, competitive and cooperative elements in the environment and the vehicle. For example, in order to evaluate the AI based decision aiding technologies that are motivated by the extremely high workload of tactical strike missions in a high-threat environment, one must create a realistic representation of that high workload situation. It is virtually impossible to create a valid realistic representation and intensity of the tactical environment other than in flight. NRCFRF offers the opportunity to integrate simulation with flight test to create the most realistic situation possible. It should be possible to conduct R&T tests with M on N engagements with actual aircraft in flight and simulate other threats such as surface-to-air missiles (SAMs) and most of the offensive and defensive weapons. The new technology, such as a new situational awareness display, could be included in one of the aircraft and evaluated in this most realistic environment.

The major choke-point and design-critical issues involving the human operator's roles in accomplishing integration in the new era will be: divided attention operations; graceful degradation properties; situational awareness; and, stress-induced impairments. The following crew-vehicle systems R&T drivers are identified as potentially benefiting from use of NRCFRF capabilities; pilot-vehicle input interface; pilot-vehicle output interface; and, pilot vehicle system interactions.

Pilot-Vehicle Input Interface

Under Pilot-Vehicle Input Interface are situational awareness and supercockpit displays and non-visual display modalities. The degree of "situational awareness" achieved is measured objectively by task performance, pilot dynamic behavior, and utilization of particular display "information components" during divided attention operations. Other measures, such as pilot commentary about display effectiveness, a posteriori understanding, and workload, provide important subjective indicators. Critical cases require the simulation or creation of very high veridical workload where realistic divided attention conditions are virtually impossible to achieve without recourse to the flight environment. The NRCFRF is needed to provide the level of computing necessary for concept development and demonstration of visual situation displays as well as the extensive data handling and on-line or near real-time computation additionally required for measurement and assessment. By handling the outer loop and environmental information processing, display generation signals, etc., in the ground-based computer, concept generation and concrete demonstration could be accomplished several "computer generations" ahead of what could be done with airborne facilities. The NRCFRF would similarly assist in the non-visual display modalities such as voice, tactile, and proprioceptive displays. Because these are generally intended to supplement, heighten, and confirm visual information in the presence of high workload, divided attention conditions; the argument given above applies here as well.

Pilot-Vehicle Output Interface

In the area of Pilot-Vehicle Output Interface, are manual (hand, feet, head movement, etc.) and voice-actuated manipulations. For concept development, assessment, and demonstration; the flight environment is again essential to provide appropriately-correlated motion and visual cues and some vertical divided attention demands. Voice-actuated manipulation, voice recognition in the flight cockpit mileau, and assessment techniques are all computationally driven. Again, the NRCFRF is required for the earliest possible test and demonstration of these devices.

Pilot-Vehicle Systems Interactions

In the area of Pilot-Vehicle System Interactions, a major problem is the development of a task-tailored controller. The nature of transitions between various task-tailored automatic flight control systems (AFCS) modes is dependent on flight motion-visual-task environment. Again, as noted above, critical high workload, divided attention conditions are virtually impossible to achieve without recourse to a flight environment. In addition, a veridical motion environment is particularly important for task-oriented AFCS developments. The measure of pilot workload alleviation again involves task performance, display effectiveness, and "information component" utilization during divided attention operations. A NRCFRF would provide the level of computing necessary for the development of task-tailored outer loop and environmental information processing, the development of display generation signals, as well as providing for the data handling and associated computation needed for measurement and assessment.

3.1.3 Experimental/Advanced Aircraft Testing

NASA DFRF has a rich history of testing all types of experimental aircraft, such as the X-15, lifting body vehicles and HiMAT, as well as advanced aircraft under development by DOD, such as the century series fighters in the late 1950s and 1960s, the FY-14 and 15 STOL prototypes, FY-16 and FY-17 prototypes and, more recently, the F-14 and F-18. NRCFRF capabilities would not only be beneficial to testing future experimental vehicles and advanced aircraft, but also in conducting flight research using other test-bed aircraft to develop and validate requirements for developing such vehicles.

National Aerospace Plane

Under experimental/advanced aircraft testing, a major experimental vehicle program which could benefit from a NRCFRF capability is the National Aerospace Plane (NASP). Precise trajectory guidance could be computed on the ground using an extensive data base updated by real-time test data and up-linked to NASP. Optimal flight profiles could be flown to minimize heat load or maintain precise test conditions for obtaining quality test data. Extensive real-time analysis of the flight test data could help assure that the test data are adequate. It could also be used to control the experiment, for example, if results look questionable at one test point it could be repeated before going on to the next. This could improve the quality of information for each flight and make it much more efficient. Critical parameters could be predicted a few seconds into the future by using real-time test data to update models of the systems for comparison with a safety hypersurface to warn of a potential safety problem. Takeoff/abort and terminal phase control monitoring and command guidance could be done very precisely through real-time update of an extensive data base, optimal state estimation and trajectory optimization. It would also be possible to compute synthetic landing aids as a backup system. It may be possible to off-load a portion of the onboard computing requirements by computing non-critical mission avionics functions on the ground. The sensors and pilot vehicle interface systems would be onboard. Each of these potential concepts need to be analyzed in more detail to determine which are feasible. The NASP experimental vehicle flight test program is one of the examples selected to illustrate NRCFRF in a later section.

Over the next several years, a number of flight tests should be conducted to help define requirements and/or evaluate potential operational concepts for NASP before the design specifications are prepared. Some examples are: stability and control/ handling qualities; sink rate for landing gear requirements; and, energy management/engines requirements. NRCFRF could provide a "veriable stability and performance" capability with an existing test aircraft such as F-18 to conduct parametric studies. Flight tests using NRCFRF would also be needed to validate the testing techniques and algorithms to be used for the NASP flight testing.

Classified Programs

Classified and special access aircraft programs could also use the full capabilities of NRCFRF, but most likely through a remote site operation.

Advanced Aircraft Testing

In the aircraft testing area, the ATF and ATA programs could make use of the NRCFRF for flight experiments using research aircraft to establish requirements and evaluate new technology. The capabilities needed would include expanded remote vehicle augmentation, system reconfiguration, integrated controls, real-time nonlinear simulations, and pilot workload/situation awareness measurements, all of which require extensive computational power. In addition, the facility could provide test environment computations for conducting ATF/ATA prototype flight tests to explore safety issues and investigate advanced systems applications.

The facility would be ideal for testing high angle-of-attack research vehicles by providing nonlinear multivariable control algorithms for integrated thrust vector and flight controls experimentation.

The LHX program could benefit from air-to-air combat and nap-of-the earth flight experiments on a research vehicle, such as ADOCS, to establish and evaluate characteristics prior to actual flight of the LHX. Two examples of possible test programs are provided. In the first example, an advanced rotorcraft concept such as a tilt-rotor (XV-15) could be evaluated with various experimental systems (i.e., glass cockpit) in a combat scenario. The purpose of the evaluation would be to obtain preliminary design information for a program such as LHX. Several red and blue players would be provided to insure a realistic threat environment in various realistic terrain scenarios. Using the NRCFRF, various flight control systems, cockpit display configurations, or tactics might be evaluated without requiring the tilt-rotor to have onboard any equipment other than the reprogrammable displays and up-link/down-link equipment to interface with the ground computer. These types of control/display/ flight control evaluations are now done on a simulator such as the NASA Ames Vertical Motion Simulator. Their validity, however, is often highly questioned due to real or perceived problems related to visual equipment, motion equipment, and rotorcraft mathematical models, as well as inappropriate combat and terrain scenarios where the pilot is not required to accomplish tasks other than flying the rotorcraft. In a more extreme test of the capabilities of the rotorcraft concept, such effects as electronic jamming, electronic counter/countermeasures (i.e., chaff), and high levels of communication traffic could also be included in the scenarios to build up pilot workload.

A second example of a test that might be conducted would be one in which several generic rotorcraft (surrogate LHXs) are configured with "simulated" advanced control, weapon, communication, and navigation systems (through a programmable set of cockpit CRTs) to evaluate pilot workload and tactics in day or night combat. It was discovered from a test at Fort Hunter-Leggett that crew workload (for the level of training provided) using the "production cockpit" was almost insurmountable for the tactics and scenarios being evaluated (which were deemed to be the correct ones that were most realistic for European combat). If this test could have been preceded by a test several years in advance using a reconfigurable cockpit and a surrogate helicopter, then alternative display formats, control system concepts, automation concepts, and even training requirements could have been evaluated to obtain some "smarts" on how to define and interface the future production cockpit before it became too late to change things because of cost.

These would entail such NRCFRF capabilities as: expanded remotely augmented vehicle functions; real-time nonlinear simulation; and, pilot/vehicle interactions. In addition, the facility would be ideal for prototype flight tests because of the extensive instrumentation and computational capacity afforded for environmental safety and advanced systems investigations and verifications.

3.1.4

Flight Testing Environment and Support

Flight testing environment and support is the last of the four categories addressed under R&T drivers. Three specific areas are identified: flight test scenario simulation; flight safety support; and, experimental data support.

Flight Test Scenario Simulation

Simulations of flight test scenarios involving realistic tasks and stress, threats, and weapons are computationally intensive because of the requirements for real-time generation of data associated with offensive and defensive weapons and multiple threats as well as the audio/visual burden. For example, NRCFRF might be used to create a simulated combat scenario that would be used in combination with flight test to create a realistic high workload environment for testing advanced technologies such as those from the Pilot's Associate (PA) program. In this example, the aircraft with the PA starts at the friendly airstrip with a pre-planned route to some target which is protected by surface-to-air missiles (SAMs), and anti-aircraft artillery (AAA), as well as interceptors at the enemy airstrip. All the ground-to-air threats would be simulated in detail and displayed to the pilot on a horizontal situation display, if and when appropriate, and possibly missiles in flight could be displayed on a helmet mounted display. The interceptor might be an actual fighter aircraft. Offensive and defensive weapons would be simulated. The PA would then be flight tested in this realistic high-work-load tactical environment. The scenario could be varied in a number of ways to stress the PA and pilot combination in a very controlled experimental manner.

Flight Safety Support

The facility could provide flight safety support for collision/terrain avoidance and performance limitations, by providing the necessary real-time computations and up-linking warning and/or command guidance information to the test pilot. For example, if a helicopter test flight program involved NOE and air-to-air combat with multiple red and blue aircraft, one would be concerned over potential collisions in the air or with the terrain. If one of the helicopters was equipped with an advanced technology single-pilot cockpit to be evaluated in an extremely high workload situation, it would be important to provide extra safety monitoring because of the pilot's divided attention. NRCFRF could monitor all the aircraft, there relationship to each other and the local terrain. In addition, having the aircraft state vectors for all the aircraft would allow computing predictions of potential collision courses and provide warning and/or guidance commands to all aircraft involved.

Experimental Data Support

Experiment data support requires extensive real-time data processing and simulations which the NRCFRF could readily provide for such functions as experiment control, real-time analysis, result predictions and on-line validation. Examples of this are included in the NASP experiment example to follow.

3.1.5 Summary of Computational Drivers

Figures 5 to 8 provide a summary assessment of the remote computational drivers for the four R&T requirements areas: advanced flight systems, crew-vehicle system integration, experimental/advanced aircraft testing, and flight test support. The relative benefits of using remote computation in each area is assessed as high, medium, or questionable as noted.

In the technology area of computer science and artificial intelligence (AI), the benefits are most pronounced in the development of advanced flight systems (Figure 5). Under the heuristic/algorithmic assessments area of AI, particularly damage/failure assessments, crew performance and flight test monitoring, the benefits span the indicated development activities.

In the technology areas associated with computationally driven guidance and control algorithms (Figure 6), the advanced flight system development area was identified as one which would greatly benefit from the availability of remote computational capability over a wide spectrum of technology activities from real-time trajectory optimization to adaptive controls. It was also found that flight test trajectory control, energy management and variable stability airplane type of computations would be beneficial to the various development activities as shown.

The various facets of crew-vehicle interface technology would derive benefit from remote computational capability. As indicated in Figure 7, they would be particularly attuned to developments in the areas of advanced flight systems and crew-vehicle system integration and crew performance assessment technology would benefit all the development activities noted.

The flight test support technologies shown in Figure 8 are all computationally intensive activities and, thus, would benefit highly from remote computational capability in association with the development areas indicated.

3.2 Example Experiments and Justification for Flight

The two examples chosen to illustrate the R&T drivers, the potential benefits of the remote computational facility and the justification for flight testing are: (1) the Robotic Wingman (RW); and, (2) the National Aerospace Plane (NASP)

COMPUTATIONAL DRIVERS	ADVANCED FLIGHT SYSTEMS	CREW-VEHICLE SYSTEM INTEGRATION	EXP/ADVANCED AIRCRAFT TESTING	FLIGHT TEST SUPPORT AND ENVIRONMENT
COMPUTER SCIENCE/AI				
COORDINATED REAL-TIME EXPERT SYSTEMS COUPLED WITH ALGORITHMIC CONTROLS	●	●	○	
REAL-TIME PLANNERS	●	●	○	
VOICE RECOGNITION AND ACTUATION	●	●	○	
VISION UNDERSTANDING	●	○	○	
IMAGE PROCESSING	◒	○	○	
SAR PROCESSING	◒	○	○	
HEURISTIC/ALGORITHMIC ASSESSMENTS (INCLUDING KNOWLEDGE BASED SYSTEMS)				
- DAMAGE AND FAILURES	●	◒	●	●
- PERFORMANCE (i.e., CREW)	●	●	●	●
- MISSION	●	○	●	○
- MAINTENANCE	◒	○	◒	○
- FLIGHT TEST MONITORING	●	●	●	●

REMOTE COMPUTING BENEFIT

● - High
◒ - Medium
○ - ?

FIGURE 5. SUMMARY OF COMPUTATIONAL DRIVERS

COMPUTATIONAL DRIVERS	ADVANCED FLIGHT SYSTEMS	CREW-VEHICLE SYSTEM INTEGRATION	EXP/ADVANCED AIRCRAFT TESTING	FLIGHT TEST SUPPORT AND ENVIRONMENT
GUIDANCE AND CONTROL ALGORITHMS				
TRAJECTORY REAL-TIME OPTIMIZATION	●	○	●	
PERFORMANCE SEEKING CONTROLS	●	○	○	
INTEGRATED CONTROLS - PROPULSION/FLIGHT CONTROL - IFFC/IFPC	●	○	◒	
FLIGHT TEST TRAJECTORY CONTROL	●	○	●	●
ENERGY MANAGEMENT	◒	◒	●	●
"VARIABLE STABILITY AIRPLANE"	●	●	●	
NON-LINEAR AND ADAPTIVE CONTROLS	●	●	○	

REMOTE COMPUTING BENEFIT

● - High
◒ - Medium
○ - ?

FIGURE 6. SUMMARY OF COMPUTATIONAL DRIVERS (continued)

COMPUTATIONAL DRIVERS	ADVANCED FLIGHT SYSTEMS	CREW-VEHICLE SYSTEM INTEGRATION	EXP/ADVANCED AIRCRAFT TESTING	FLIGHT TEST SUPPORT AND ENVIRONMENT
CREW-VEHICLE INTERFACE				
CGI SITUATIONAL AWARENESS DISPLAYS	●	●	○	●
DISPLAY PANEL INFORMATION GENERATION	●	●	○	●
HELMET MOUNTED DISPLAY GENERATION	●	●	○	●
VOICE RECOGNITION/SYNTHESIS	●	●	○	
3-D SOUND SYSTEMS	●	●	○	
MINIPULATOR FUNCTIONS	○	○	○	
CREW PERFORMANCE ASSESSMENT/MEASURES	●	●	●	●

REMOTE COMPUTING BENEFIT

● - High
◒ - Medium
○ - ?

FIGURE 7. SUMMARY OF COMPUTATIONAL DRIVERS (continued)

COMPUTATIONAL DRIVERS	ADVANCED FLIGHT SYSTEMS	CREW-VEHICLE SYSTEM INTEGRATION	EXP/ADVANCED AIRCRAFT TESTING	FLIGHT TEST SUPPORT AND ENVIRONMENT
FLIGHT TEST SUPPORT				
REAL-TIME SIMULATIONS				
- WEAPONS (OFFENSIVE & DEFENSIVE)	●	●	●	●
- THREATS	●	●	●	●
- TARGETS	●	●	●	●
- AIR TRAFFIC	●	●	●	●
- BATTLE SCENARIOS	●	●	●	●
- ELECTRONIC WARFARE	●	●	●	●
FLIGHT SAFETY LIMIT HYPERSURFACE	●	●	●	●
PREDICTION OF EXCEEDING LIMITS	●	●	●	●
TRAJECTORY CONTROL ALGORITHMS	●	○	●	●
REAL-TIME DATA PROCESSING	●	●	●	●
MONITORING DISPLAY INFORMATION	●	●	●	●

REMOTE COMPUTING BENEFIT

● - High
◒ - Medium
○ - ?

FIGURE 8. SUMMARY OF COMPUTATIONAL DRIVERS (concluded)

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experimental vehicle. The RW example is presented in detail in Volumes IV and V of the study and, therefore, will not be covered here. The NASP example, covered in this section, was only defined to the extent necessary to describe and substantiate the R&T drivers and the remote computational facility concepts. The justification for flight testing is treated within each example.

3.2.1 National Aerospace Plane

The National Aerospace Plane (NASP) program is a high technology transportation concept designed to provide options for the next generation of commercial and military aerospace vehicles. It includes technology development for reusable air-breathing hypersonic/trans-atmospheric vehicles. The plan is to establish and validate a technology base by the mid-1990s by conducting both ground-based developments and testing, and experimental research vehicle flight testing. Ground-based activities include airbreathing propulsion, advanced materials, computational fluid dynamics and actively-cooled structures. Experimental flights are to include horizontal takeoff and conventional runway tests, single stage-to-orbit flight and hypersonic cruise.

Much of the material used here relating to the NASP program was taken directly from or are derivatives of material presented at the Ames Research Center in December 1986 at a meeting of the Aeronautics Advisory Committee and the Aerospace Research and Technology Subcommittee. The material was used in the Vehicle Program Review portion of the meeting.

Figure 9 highlights the major technologies involved in the development of an aerospace plane. The most critical aspect to the viability of NASP is the airbreathing propulsion system which intimately involves the aerodynamic configuration for for-body compression and afterbody expansion and an intricate control system. The intense heating environment and desired operational objectives (inappropriate for Shuttle type thermal protection system) requires new technology in hot structures and probably active cooling using liquid hydrogen as the coolant. Active controls will be used for reduced/negative static stability augmentation and flying qualities. The fuel may be used for active CG control as well as an active thermal energy management. The NASP Experimental vehicle development and flight test program will be very challenging.

The requirements of airbreathing propulsion from earth to orbit flight plus the mission requirements for a variety of flight plans makes the NASP flight envelope much more challenging on technology than the Space Shuttle. Other than for emergencies, the Shuttle stays in very narrow corridors about its ascent to orbit and re-entry/descent trajectories. The intense heating regime for the Shuttle is from about M=22 to 15 which it passes through quickly. On the other hand, the intense heating regime for NASP could be from about M=25 to 5 depending on the altitude flown. NASP would have the capability of sustained flight in these intense heating conditions rather than passing through as with the Shuttle. It is possible to have unpredicted aerothermodynamic effects that could create extreme hot spots in very short time periods which would jeopardize structural integrity. Having precise control over the trajectory flown, an excellent insight into the flight test data in real-time, and effective and reliable safety monitoring will be essential for the NASP Experimental Vehicle flight program. NRCFRF could assist in all three aspects and more. Actually, five specific areas have been identified in which NRCFRF would benefit NASP: (1) precise trajectory guidance and control; (2) real-time experiment analysis and control; (3) safety monitoring/warning; (4) takeoff/abort and terminal phase control; and, (5) non-critical mission avionics.

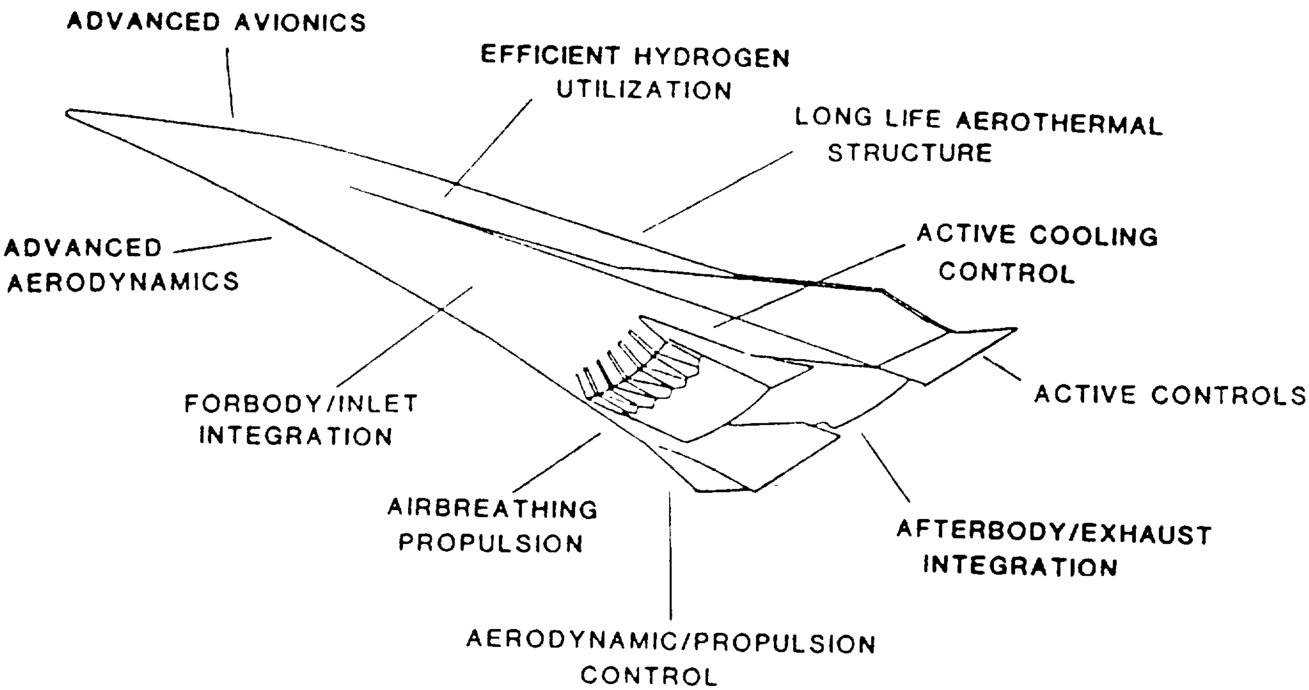

FIGURE 9. KEY AEROSPACE PLANE TECHNOLOGIES

Precise Trajectory Guidance and Control

NRCFRF could provide a much more extensive computing power than onboard computers which means more accurate models and data bases could be used and updated in real time. The result is much more precise guidance and control which is needed to assure high quality flight test data. Precise control of critical flight test conditions will be needed to verify specific ground test data at the lower hypersonic Mach numbers before proceeding to the higher Mach numbers where there will not be any equivalent ground test data. Precise control is also needed to avoid exceeding critical limits such as, thermal load, inadvertantly. It may be desirable to fly a precise pre-programmed test profile as a function of Mach number, altitude or some other variable such as rate of change of thermal load, to a specific set of test data.

The extensive ground computational power makes it possible to provide "real-time" optimal flight path guidance and/or control to minimize or limit thermal load; to fly minimum time or fuel profiles to specified end conditions; to minimize fuel to orbit and/or re-entry to terminal conditions; to fly minimum fuel sorties; or other similar objectives. Onboard processing of the type that will probably be available for the experimental vehicle would have to perform multiple G&C functions and could not devote adequate capacity to provide highly accurate models and sophisticated algorithms to perform such a variety of optimal flight path guidance.

Real-Time Experiment Analysis and Control

With NRCFRF, the experimenter becomes an integral and active part of conducting the flight test because of the availability of real-time "results" not just data. These results can be used to redirect the test in real time. NASA DFRF has been developing and expanding the capability to perform analyses on real-time telemetry data for several years. The idea here is to further expand that capability to cover the experiment requirements of NASP. Accurate real-time test results will be critical in the flight envelope expansion phase of flight testing. For example, net thrust cannot be measured directly in flight and at the hypersonic speeds it is a relatively small number that is the difference between two very large numbers. Extensive real-time processing may be needed to provide accurate estimates at net thrust from the measurements that can be taken, e.g., acceleration, pressure distributions, temperatures, air density, Mach number, fuel flow, etc. Accurate estimates of the net thrust in real-time is important in conducting the flight tests from an energy management standpoint. Real-time analysis is also important to estimate and predict thermal loads, heat transfer in critical areas, hot spots, vehicle stability and others.

Accurate real-time test results are important for efficient and expeditious conduct of the flight test program. Flight test plans are always a compromise between the number of test conditions that the experimenters want and test time available. If the test results can be compared to the predicted results adjusted to the real test conditions rather than the planned conditions, one can verify the results rapidly and even adjust the test plan in real-time based on the results. When anomalities occur, which they always do, you may not have to terminate a flight if sufficient real-time analysis can explain them and/or indicate additions tests needed to help explain them. The lack of real-time results would force a more conservative flight schedule.

Safety Monitoring/Warning

The combination of the first two provides the basis for extrapolating the results a few seconds into the future in real time to monitor critical flight safety parameters. Warnings can be given of potentially exceeding allowable limits. If a good mathematical model or simulation exists for critical parameters, such as vehicle stability or aerothermodynamic loads at a critical location, then it should be possible to predict future values of the critical parameter to some degree of accuracy. Those predicted values could be compared to allowable safety limits and the flight plan changed if it appears that a limit might be exceeded. The problem is that during the flight envelope expansion where this is most important, there are no previous flight data to verify the mathematical models. With NRCFRF one might be able to verify and update the models in real-time then extrapolate into the future with the updated model in a "boot strapping" mode.

Having the variety of optimal flight path guidance capability discussed previously would be valuable in emergency conditions to compute a multitude of options of any point in the flight envelope.

The potential use of real-time expert systems to assist in safety monitoring and issuing advisories should be considered since NRCFRF would have the capability of implementing such systems.

Takeoff/Abort Terminal Phase Control

Trajectory algorithms and extensive data bases updated in real time provide the basis for accurate energy management which is important during takeoff and terminal phases and emergency situations, such as an abort. Multiple flight path options could be computed continuously during takeoff to provide alternate "normal" paths and emergency paths in case an abort is necessary. It could recommend the "best" abort option at any point and provide that as guidance commands on request. Onboard processing would be very limited in the accuracy of energy management information and the variety of options possible.

The remote computation of trajectories could also provide an alternate source for precision/aiding guidance, in effect a synthetic landing aid. The ability to control landing conditions precisely can have a significant impact on the vehicle design. For example, if the sink rate at touchdown could be controlled to precise limits, the weight of the landing gear and support structure could be minimized. However, the landing guidance system becomes critical and redundancy would be required. The NRCFRF could be used as one channel of the redundant system.

Non-Critical Mission Avionics

The data links can be thought of as essentially extend the onboard avionics bus to the remote computation capability on the ground. Computationally extensive avionics concepts could be evaluated in flight with the NRCFRF well before flight qualified computers are available.

The various missions that DOD will want to evaluate and/or demonstrate with the NASP experimental vehicle are likely to require an extensive avionics suite. In fact, the number of avionics functions and degree of capabilities desired will probably exceed any reasonably weight and space allocation. If the computations can be done remotely and the data link requirements integrated with that of the other real-time flight test support system, it may be possible to reduce the weight and volume of the onboard systems. More importantly, it may be possible to evaluate a functional level of technology a couple of generations beyond that which would be available in flight qualified hardware at the time of the experimental flight tests. The computational technology is progressing so rapidly that by the time an operational military vehicle is developed it would use a newer generation of avionics hardware technology than would be demonstrated with flight qualified hardware on the experimental vehicle.

Possible Remote Computational and Data Link Concept

Figure 10 shows an example of how the remote computation capability could be used via data links to support NASP. This might illustrate the final quarter of a Mach 15 sub-orbital flight test. A Remote Airborne Platform (RAP) would be used to relay data to and from NASP and DFRF either directly or via the Tracking and Data Relay Satellite (TDRS) and to perform some other remote computations (see Section 4.2.2 for details). The RAP could cover a range of 400 nautical miles in radius or 800 nautical miles total maximum coverage. At Mach 15, that would amount to about 6 minutes of coverage. All the NASP telemetry would be down-linked via RAP to DFRF. Certain data would be tapped off at RAP to use in local calculations. For example, trajectory algorithms might be calculated at RAP and the guidance commands up-linked to NASP directly to minimize transmission delays. The information required to update in "real-time" the models and data base used in these algorithms could be calculated at DFRF from the relayed data and up-linked to RAP. Updating the models and data base take more analysis and more time than is available between required updates of the guidance algorithms. Similar division of the computational load would be made for each task. Those requiring the highest update rate would be calculated at RAP and others would be done at DFRF.

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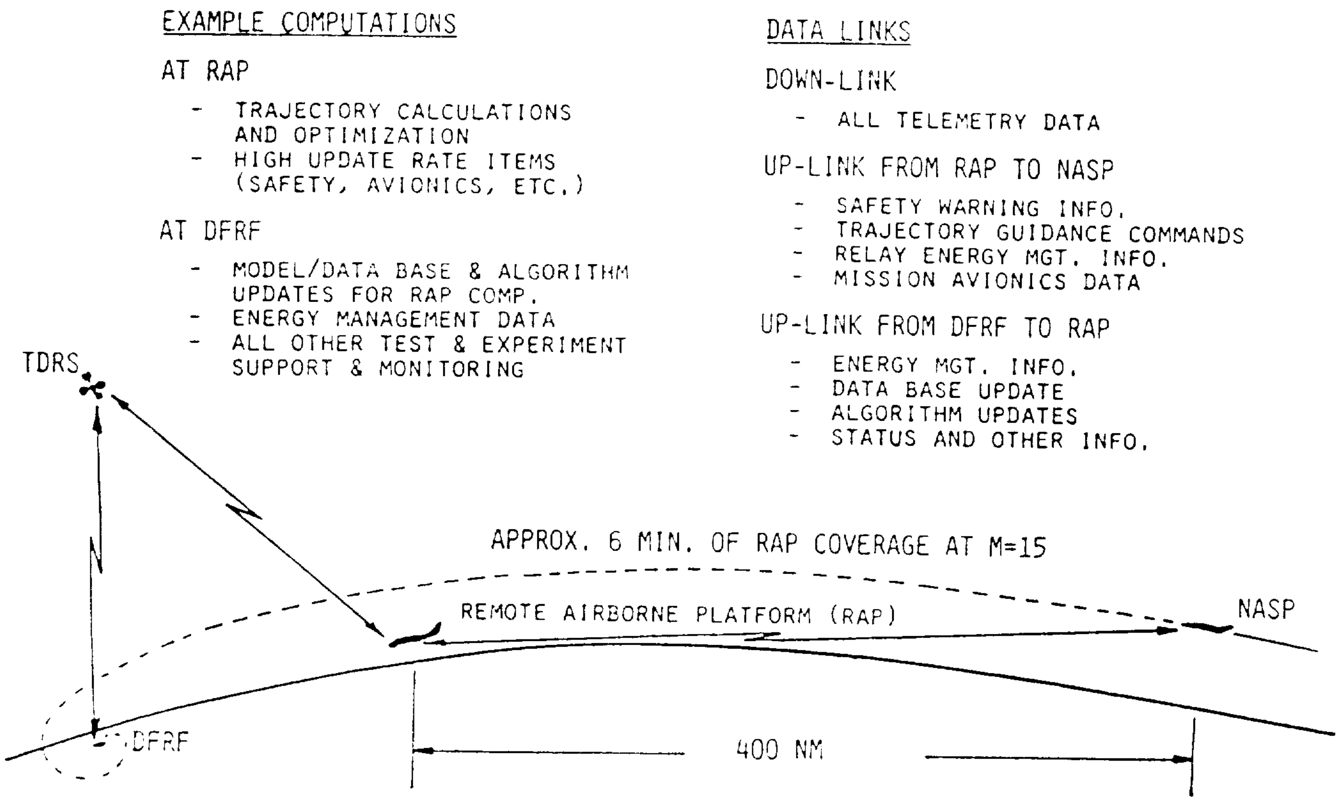

FIGURE 10. POTENTIAL REMOTE COMPUTATION AND DATA LINK CONCEPT

Potential Benefits of NRCFRF Support

The NRCFRF would appear to have significant potential for supporting the NASP flight testing program and indeed could have significant impact on the experimental vehicle design itself. NASA will need the highest quality flight experiment data possible and yet the conditions under which the test data will be collected may be quite severe. The experimental aircraft program will be highly visible in spite of its classification. Considerable pressure will exist to accelerate the "experimental" phase and get on to the military mission assessments. Extensive remote computation performed in real-time to monitor and possible even control the experiments could assure higher quality data and a better understanding of results and anomalies. Having precise control over the flight experiments and a good understanding of the results in real-time would increase the likelihood of achieving the objectives under a pressured schedule situation. NRCFRF could provide an interesting option for evaluating certain DOD mission avionics functions generations before flight qualified hardware is developed and/or evaluating alternate avionics concepts without having dedicated hardware for each concept.

Justification for Flight Testing

NASP clearly requires a flight test program to develop and validate the technology base for operational hypersonic vehicles. The NASP performance range cannot be duplicated with currently available ground facilities. A key item is the propulsion system. Current wind tunnels can test engines up to about Mach 8 which is substantially below the expected range of Mach 25. There are gaps in fluid dynamics analysis capabilities over the expected range, which necessitate a flight environment.

It is axiomatic that the true flight environment cannot be adequately simulated. This is particularly true with highly integrated systems such as the NASP vehicle. Consequently, flight tests are required to validate the airframe/propulsion system interactions and to detect/evaluate any unforeseen system interactions. The cost in time and resources to turn around the NASP vehicle are very important to its operational realization. These can only be realistically assessed through actual flight operations.

Flight tests will provide the DOD a means of developing and evaluating potential operational strategies associated with the emergence of a new fleet of earth-to-orbit vehicles.

4.0 TEST RANGE AND FACILITIES CONSIDERATIONS

NASA has made a major investment in the test range and facilities at DFRF and WATR to the point where they are the finest in the USA for the type of flight research and testing conducted by NASA Ames/Dryden. The information on the WATR and planned expansions was obtained from Reference 1 and discussions with the DFRF staff. This section addresses the test range and facilities considerations to provide the capabilities to support the R&T requirements defined in Section 3.0. The WATR and other DFRF facilities were used as the baseline for this study. The intent of the study was to identify new capabilities that would be added and integrated with the existing systems and facilities. For example, the WATR includes an extensive real-time processing and display systems to provide real-time information for mission decisions. This study suggested a need to further expand that capability for additional flight experiment support.

Figure 11 is an estimated schedule for the major programs suggested as potential users of NRCFRF. The dashed lines are

TABLE 1.

POTENTIAL PROGRAMS FOR NEAR-TERM FACILITIES (1987 to 1993)

- o ROBOTIC WINGMAN CURRENT PROGRAM
- o PILOTS ASSOCIATE FLIGHT DEMONSTRATION: PHASE I
  - INDIVIDUAL SYSTEMS
  - COOPERATIVE EXPERT SYSTEMS
- o AUTOMATED NOE CURRENT PROGRAM
- o AUTONOMOUS AIR VEHICLE AVIONICS FLIGHT DEMONSTRATOR
- o F-15 STOL MANEUVER DEMONSTRATION
  - RECONFIGURABLE CONTROLS
  - ADVANCED HIGH AOA CONTROL
  - ADVANCED INTEGRATED CONTROLS
- o X-WING DEMONSTRATION
  - REAL-TIME FLIGHT TEST SUPPORT
  - ADVANCED CONTROLS
- o HIDEC
  - PERFORMANCE SEEKING CONTROL
- o F-18 HARV
  - ADVANCED HIGH AOA/NON-LINEAR CONTROLS
- o NASP RESEARCH AND DEVELOPMENT FLIGHT TEST
  - TO SUPPORT REQUIREMENT DEFINITION
  - VALIDATE TECHNIQUES FOR EXPERIMENTAL VEHICLE FLIGHT
- o ATF AND LHX R&D FLIGHT TEST
  - EVALUATE NEW TECHNOLOGY
  - VALIDATE FLIGHT TEST REQUIREMENTS AND METHODS
- o AIRCRAFT INTERNETTING (STAND ALONE SYSTEM)
- o SYSTEM MONITORING/MAINTENANCE
- o CREW-VEHICLE SYSTEMS INTEGRATION ISSUES
  - REAL-TIME SITUATIONAL AWARENESS MEASURES
  - SITUATIONAL AWARENESS DISPLAY RESEARCH (CURRENT COCKPIT SYSTEMS)
  - TASK-TAILORING DISPLAYS AND CONTROLLERS
- o DEVELOP AND VALIDATE HARDWARE/SOFTWARE FOR FLIGHT TESTING ENVIRONMENT AND SUPPORT FUNCTIONS
  - EVOLVE INTO FAR-TERM SYSTEM

TABLE 2.

POTENTIAL PROGRAMS FOR FAR-TERM FACILITIES (1990 to 2000)

- ROBOTIC WINGMAN EXTENSION (1994-1999)
  - M ON N COMBAT ENVIRONMENT
  - UNMANNED DEMONSTRATION
- PILOTS ASSOCIATE FLIGHT DEMONSTRATION: PHASE II (1993-1997)
  - INTEGRATED PA SYSTEM
  - M ON N COMBAT ENVIRONMENT
- AUTOMATED NOE EXTENSION (1993-1998)
  - M ON N COMBAT ENVIRONMENT AT FT. HUNTER-LEGGETT
  - INCORPORATE AIR-TO-AIR COMBAT
- ROBOTIC AIRCRAFT OPERATIONS (1992-1999)
- SUPERCOCKPIT FLIGHT DEMONSTRATION (1992-1996)
- NASP EXPERIMENTAL VEHICLE FLIGHT TEST (1993-1997)
  - TEST TRAJECTORY CONTROL AND ENERGY MANAGEMENT
  - REAL-TIME ANALYSIS
  - SAFETY MONITORING
- NASP FLIGHT TEST EXTENSION (1997-2001)
  - ADVANCED MISSION AVIONICS FUNCTIONS
- ATF AND LHX PROTOTYPE FLIGHT TESTS (EARLY 1990's)
  - TEST ENVIRONMENT SUPPORT
  - REAL-TIME ANALYSIS
- ATF AND LHX PROTOTYPE FLIGHT TEST EXTENSION (MID 1990's)
  - ADVANCED TECHNOLOGY SUPPORT
- AIRCRAFT INTERNETTING M ON N COMBAT EVALUATION (1990-1992)
- CREW-VEHICLE SYSTEMS INTEGRATION ISSUES (1994-2000)
  - "BIG PICTURE" SITUATIONAL AWARENESS DISPLAY
  - M ON N COMBAT ENVIRONMENT
  - REAL-TIME SITUATIONAL AWARENESS MEASURES
- CONTINUED ADVANCEMENT OF REMOTE COMPUTATIONAL METHODS (1990 - 2000)

estimates of where potential add-on flight activities could be performed using the NRCFRF for the type of R&T concepts identified in Section 3.0. Tables 1 and 2 list the programs and activities into near-term and far-term program activities based on the schedule in Figure 11. These estimates are used to define the near-term, far-term facility and range considerations.

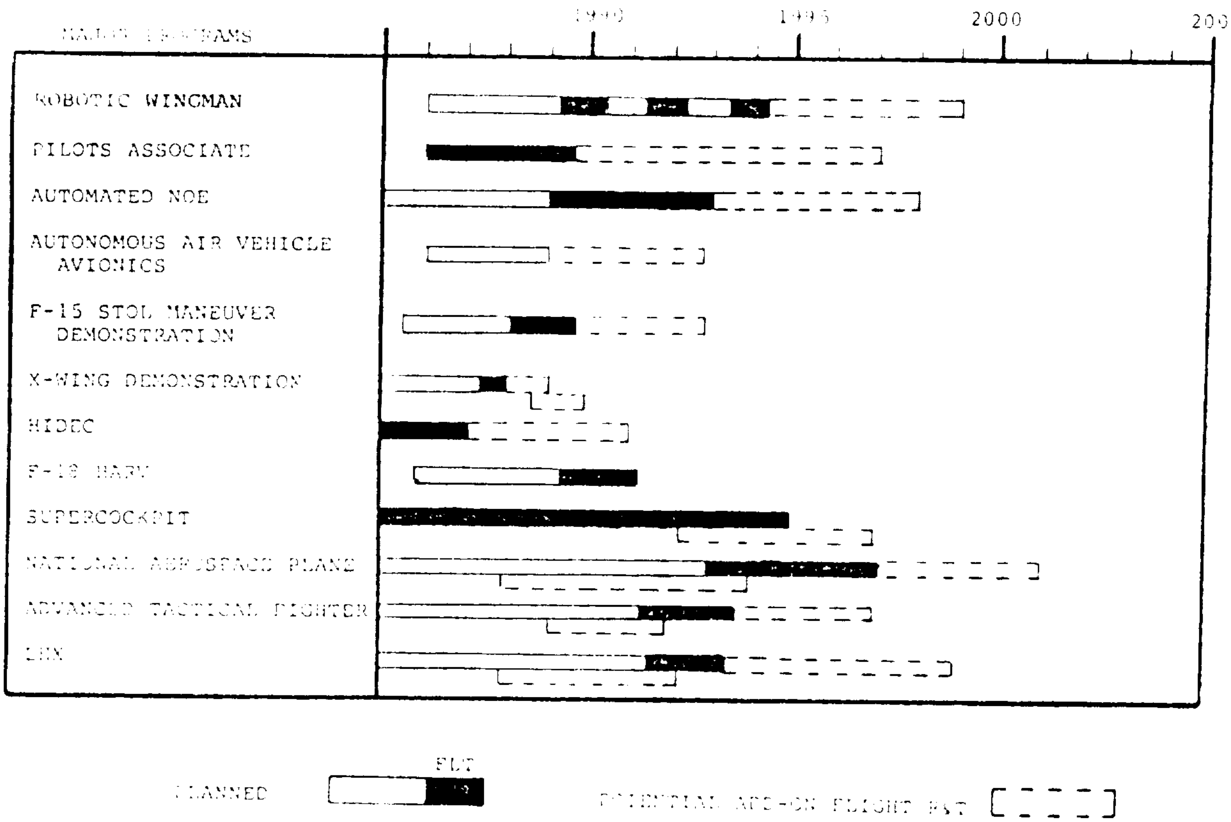

FIGURE 11. ESTIMATED SCHEDULES OF MAJOR ESTABLISHED PROGRAMS

4.1 NRCFRF Baseline Concept

This section of the report and the next (4.2), describe a conceptual NRCFRF starting with a baseline facility that would be capable of supporting all of the near-term and part of the far-term activities and expandable to support all of the far-term activities. The baseline concept, depicted in Figure 1, is discussed first. It includes: computational support; test monitoring and control; data/communication links; space positioning; vehicle interface unit; and, pilot-vehicle interface. Section 4.2 describes the extended capabilities for the far-term activities included: multi-aircraft operations; remote/mobile operations; secure systems; flight crucial functions; and, extended range operations.

4.1.1 Computational Support

Figure 12 shows the type of computational support needed for the near-term programs identified from now to about 1993. It uses the existing SEL 32/27 computers for the tracking data and telemetry interfaces. Several general purpose mini-

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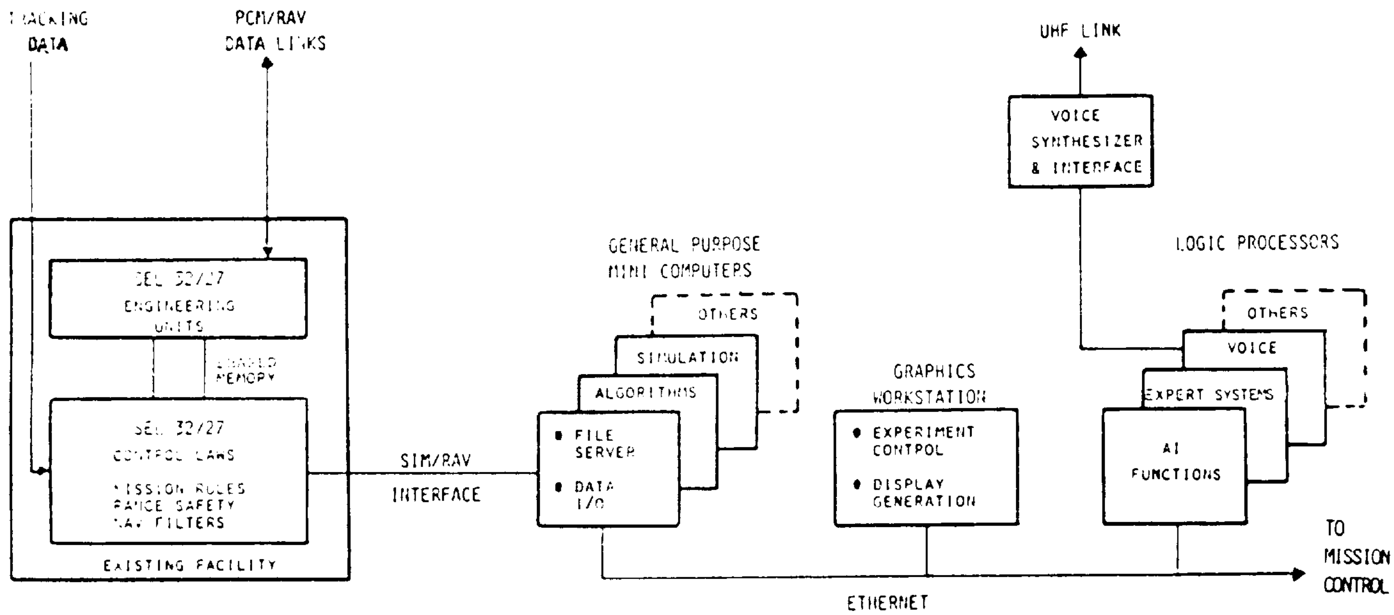

FIGURE 12. POTENTIAL NEAR-TERM COMPUTATIONAL SUPPORT ARCHITECTURE

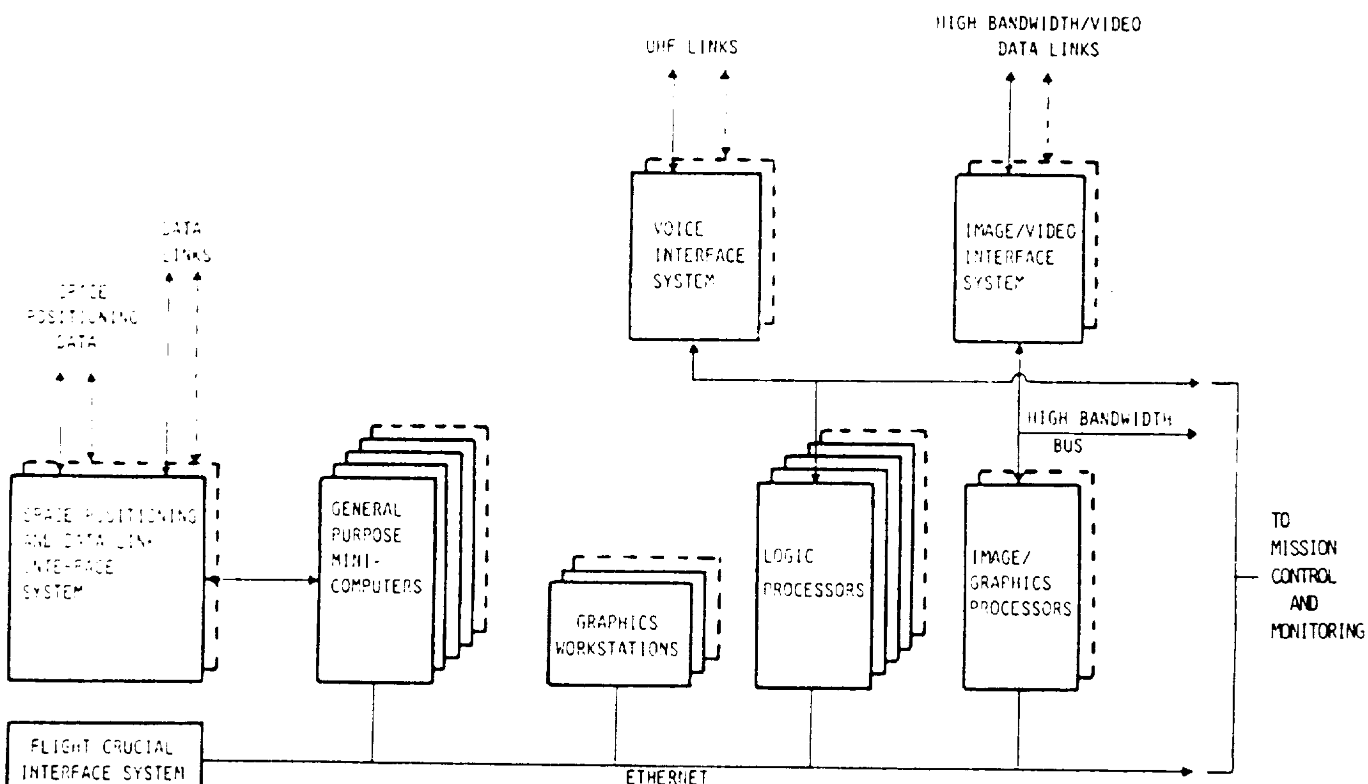

FIGURE 13. POTENTIAL FAR-TERM COMPUTATIONAL SUPPORT ARCHITECTURE

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computers (minis), such as MICROVAX-II, a graphics workstation and several logic processors, such as Symbolics 3600 or others, are connected to an Ethernet. One of the minis would be used for the inter-face with the SELs for data I/O and a file server. The other minis would be used for supporting experiment computations such as: guidance algorithms; real-time simulations and pilot work-load measures; real-time data analysis; and, flight safety. These computers need not all be the same, for example, one might be selected specifically for real-time simulation. The number of minis depends on how extensive the support requirements are in the near term. The logic processors are for various AI functions, such as expert systems, and several may be required for near-term programs. The workstation is used for monitoring and controlling the experiment as well as assisting in developing the software programs. It would be used as on interim monitor for VIP visitors. The line shown on Figure 12 from the Ethernet to mission control is to take advantage of the extensive computational power available in the mission control support systems. Those computers are currently being used for real-time flight test and experiment support. The mission control system computers could be used to augment the NRCFRF computational power. Information generated in the NRCFRF computers, such as scenario simulations, outputs from expert systems, guidance algorithms, etc., would also be available for use in the mission control room.

The Master Plan for NRCFRF should establish a system architecture that can accommodate evolving requirements and changing technology. Figure 13 illustrates the features that should be considered for the far-term programs. More than one data bus network will probably be needed, for example a high bandwidth bus may be needed for the image/video data. Also, it may be necessary to use different local buses linking several logic processors or special purpose image processors because of very high data transfer rates. The image processors are massive parallel processors designed for efficient processing of imaging data. They would be used for such processing as advanced algorithms for extracting image information that would be part of a knowledge based image understanding system. Another use would be for computer generated images to be used in the monitoring work stations and/or in the pilot displays. Multiple voice and image/video interfaces with multiple data links are shown to provide simultaneous service to several aircraft. For the far-term system, one should consider augmenting or replacing the SEL computers to service multiple aircraft simultaneously with multiple data links and computational support. The space positioning processing would integrate GPS data with other space positioning data sources. The flight crucial interface system is essentially a buffering system to allow transfer of data to a flight crucial system while blocking propagation of faults. (See Section 4.2.4) The local networks are shown to tie into the mission control and monitoring which is addressed in the following section.

4.1.2 Test Monitoring and Control

In the planning for the far-term system, one should consider an integrated approach for test monitoring and mission control as in the current DFRF Mission Control Center. The potential features of the system are listed in Table 3. The NASP program will require a global track display with the capability of displaying various trajectory and energy management information. The safety officer and engineers should have multiple displays of safety related information, such as predictions of exceeding safety limits, potential collisions and various critical aircraft parameters.

The experiment monitoring and control will require multiple large screen computer generated displays particularly for multiple aircraft operations. The large screens would be used for critical experiment information that several people need to see to make real-time decisions. Several examples of information that might be displayed are listed on the chart.

A VIP observation room should also be considered because of the increased awareness and interest in NASA's flight programs. It has become common for Congressmen and high level Executive Department individuals to want to observe first hand the accomplishments of major programs which directly effect the programs' continued support.

Figure 14 illustrates one concept of how the Mission Control Room (MCR) and VIP Observation Room (VOR) could be accommodated without compromising safety. It shows the MCR on the first floor and the VOR as a balcony. The lower half of the front wall of the VOR would be a window for observing the MCR front display wall. There would be two large screens displays on the upper half of the VOR front wall for special displays that an Observation Director could select throughout the flight. These screens could also be used prior to flight or in non-flight periods to present tutorials to VIPs so that they would better understand the flight tests.

TABLE 3.

SUGGESTED TEST MONITORING AND CONTROL FEATURES

COMMAND, CONTROL AND SAFETY

ALL FUNCTIONS AND INFORMATION OF CURRENT MISSION CONTROL ROOM PLUS:

- O GLOBAL TRACK DISPLAY ON LARGE (8' x 24') SCREEN
- O SAFETY HYPERSPHERE PREDICTIONS DISPLAYED TO SAFETY OFFICER
- O PREDICTIONS OF POTENTIAL COLLISIONS (OTHER AIRCRAFT OR TERRAIN) PRESENTED TO SAFETY OFFICER
- O FLIGHT CRITICAL AIRCRAFT PARAMETERS DISPLAYED TO SAFETY ENGINEERS

EXPERIMENT MONITORING AND CONTROL

EXTENSION OF CURRENT REAL-TIME DATA PROCESSING AND DISPLAY INCLUDING:

- O REAL-TIME SIMULATION OF EXPECTED EXPERIMENT RESULTS
- O MULTIPLE LARGE SCREEN (AT LEAST 6' x 6') DISPLAYS OF COMPUTER GENERATED GRAPHICS REPRODUCING AND POSSIBLY ENHANCING EXPERIMENT OR TEST SUCH AS:
  - CRITICAL TEST DATA (ALPHA-NUMERIC AND GRAPHS)
  - ENERGY MANAGEMENT FOOTPRINTS
  - 2D AND 3D PRESENTATIONS OF CRITICAL TEST DATA, E.G., SKIN TEMPERATURES ON A HYPERSONIC INLET OR DEVIATIONS FROM A CRITICAL TEST TRAJECTORY
  - 3D TRAJECTORIES OF MULTIPLE AIRCRAFT
  - THREATS, TARGETS AND WEAPON TRAJECTORIES
  - TERRAIN, PHYSICAL OBJECTS, AND WEATHER (INCORPORATE DIGITAL DATA MAPS)
  - PILOT'S OUT-OF-THE-WINDOW AND HUD VIEW
- O OTHER REAL-TIME INFORMATION NEEDED TO MAKE DECISIONS ABOUT EXPERIMENT PROGRESS AND CHANGES IN TESTS IF NECESSARY

VIP OBSERVATION ROOM

PROVIDE FACILITY FOR VIPs TO VIEW PROGRESS OF FLIGHT TESTS AND EXPERIMENTS IN A SEGREGATED AREA FROM THOSE MONITORING AND CONTROLLING THE OPERATIONS, E.G., BALCONY.

- O VIEW MONITORING SCREENS AND TVS
- O OBSERVE AND LISTEN TO MISSION CONTROL ROOM STAFF

PROVIDE TWO LARGE SCREENS WITH VIDEO AND/OR COMPUTER GENERATED DISPLAYS TO ASSIST LAYMEN IN UNDERSTANDING THE TESTS (LOCATED AS TO NOT DISTRACT THOSE CONDUCTING FLIGHT TESTS)

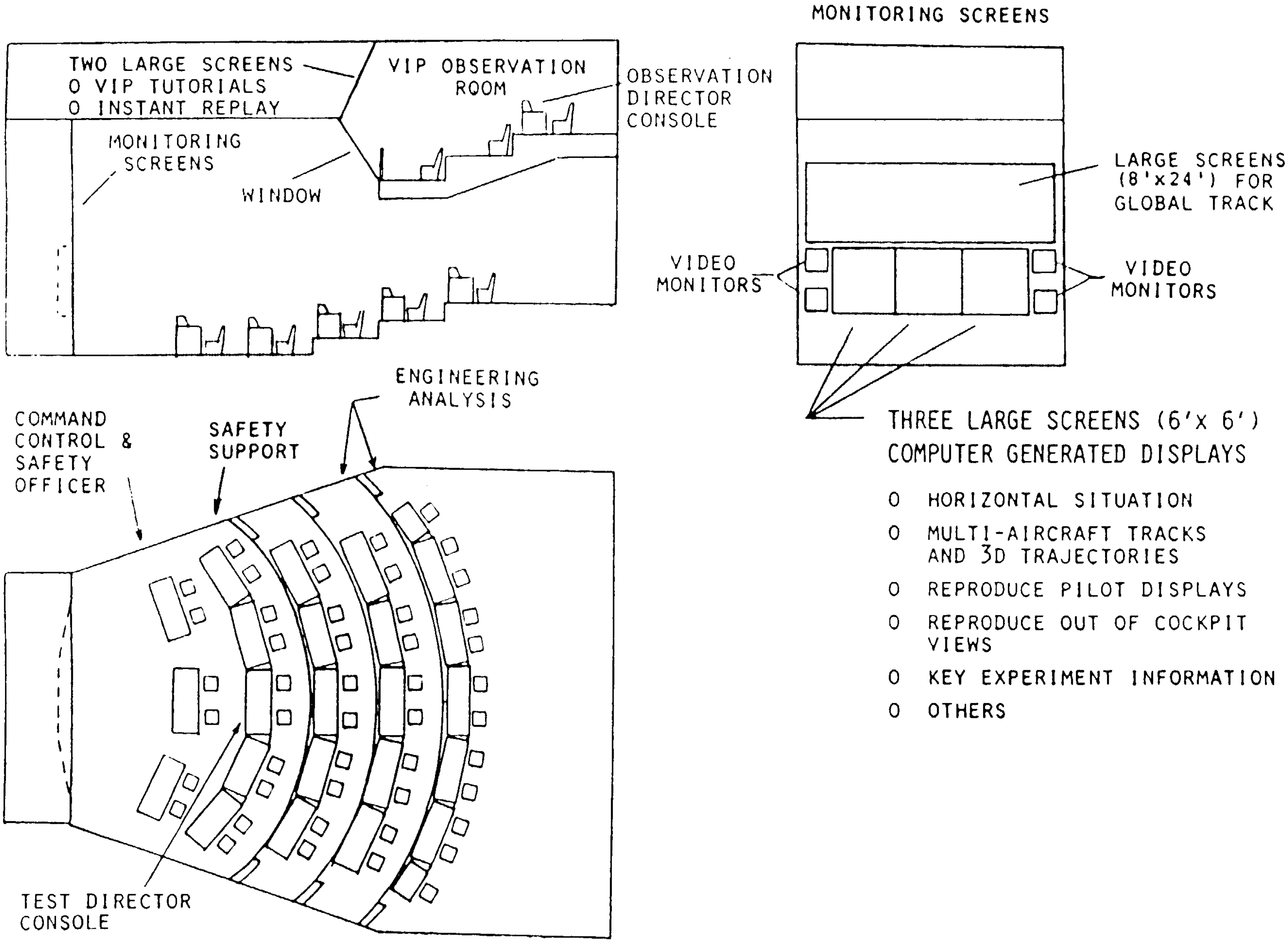
- O TUTORIALS ON PROGRAM OBJECTIVES, TECHNICAL ISSUES OR THE FACILITY
- O SIMULATIONS OF WHAT THEY WILL BE SEEING
- O INSTANT REPLAYS AND SLOW MOTION REPLAYS OF KEY TESTS OR INCIDENTS

PROVIDE VIP OBSERVATION DIRECTOR CONSOLE

- O CONTROL OVER THE VIP SCREENS
- O CONTROL OVER AUDIO SYSTEM
- O EXPLAIN EVENTS

(OPTIONAL) TIE VIP MONITORING SCREENS AND AUDIO INTO REMOTE AUDITORIUM FOR GENERAL AUDIENCE

FIGURE 14 - POTENTIAL MISSION CONTROL AND TEST MONITORING ROOM CONCEPT



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4.1.3 Data/Communications Links

The information transfer requirements to satisfy the near- and far-term programs are listed in Table 4. These are considered conservative estimates, and one should plan extra capacity within reason.

Based on the estimated information transfer requirements, it appears that the existing and planned DFRF data links are adequate for the baseline facility except possibly for the video and imaging data. It is assumed that a digital representation of the video signal is desired for mixing with other information generated in a computer or computers. Since video/imaging data drives the requirement for the high data rate links, the requirement for video and imaging data should be assessed further and defined in more depth. The 500 MBPS is typical of multi-spectral image processing and data fusion.

The principle demands on the data/communications links for the extended capabilities of the facility are multiple simultaneous data links and data relay systems. To cover the multiple aircraft programs, it would be desirable to have at least four data link sets with the full capability to be operated simultaneously. Limited data link capability should be considered for up to 8 additional aircraft. This is discussed in the Multi-Aircraft Operations Section (4.2.1).

Internetting is a term used to describe an inter-aircraft data link tied to its avionics bus to, in effect, extend the avionics bus across several aircraft. The objectives are to share avionics resources and perform closely coordinated tactical operations, such as InMASS. In addition to being a data link, it gives relative distance and bearing between two aircraft. One such system has been built and flight tested by SPARTA. Typical features are listed in this chart.

4.1.4 Space Positioning

The Global Positioning System (GPS) is ideal for the primary space positioning source because it can serve as many aircraft as needed simultaneously. Edwards AFB is scheduled to be DOD's first GPS range. Accuracy on the order of 15 meters in 3-D and 5 meters in 2-D navigation error has been measured at the test range in Yuma. The accuracy, particularly in the altitude direction and in relative range among multiple aircraft can be improved by installing a pseudo GPS satellite in the vicinity of the test range. The GPS space positioning information (including time) determined onboard each aircraft would be data linked to the ground station to track all aircraft in the tests. Several other sources of space positioning data would generally be available. The system should be designed to make use of the total set of data available in an optimal estimation algorithm such as an extended Kalman filter to produce a very accurate estimate of 3-D position. The goal should be under one meter in relative position between any two aircraft or any one aircraft

TABLE 4.

DATA/COMMUNICATIONS LINKS INFORMATION TRANSFER REQUIREMENTS

DOWN LINKS	TYPICAL NO.	SAMPLE RATES	DATA RATE
TEST/RESEARCH AIRCRAFT			
O AIRCRAFT PARAMETERS	20-100	50/1000SPS	
O SPACE POSITIONING DATA	4	50 SPS	
O TEST PARAMETERS	0-20	50 SPS	50 KBPS
O SYSTEMS MONITORING PARAMETERS			TO
- VARIABLES	0-20	50 SPS	1 MBPS
- DISCRETES	0-50	-	
O SCENARIO RELATED PARAMETER	0-10	50 SPS	
O VIDEO	0-2	30 FPS	.5-10 MBPS
O IMAGING DATA (MULTI-SPECTRAL)	0-4	20-200 FPS	10-500 MBPS
O VOICE (UFH)	1		
TEST SUPPORT AIRCRAFT (E.G., MULTI-AIRCRAFT TESTS)			
O AIRCRAFT PARAMETERS	0-20	50 SPS	
O SPACE POSITIONING DATA	4	50 SPS	1-20 KBPS
O TEST PARAMETERS	0-10	50 SPS	
O SCENARIO RELATED PARAMETERS	0-10	50 SPS	
O VOICE (UHF)	1		

UP LINKS	TYPICAL NO.	SAMPLE RATES	DATA RATE
TEST/RESEARCH AIRCRAFT			
O CONTROL COMMANDS			
- DISCRETES	0-10	-	
- VARIABLES	0-20	50 SPS	
O GUIDANCE COMMANDS	0-10	10 SPS	
O DISPLAY DATA			0-30 KBPS
- DISCRETES	0-100	-	
- VARIABLES	0-20	50 SPS	
- VIDEO	0-3	30 FPS	0-10 MBPS
O VOICE (UFH)	1		
TEST SUPPORT AIRCRAFT			
O VOICE (UHF)	1		
O DISPLAY DATA*			
- DISCRETES	0-10	-	
- VARIABLES	0-10	50 SPS	0-10 KBPS
INTER-AIRCRAFT DATA LINK			
ALL AIRCRAFT (FOR INTERNETTING TESTS)			
O AVIONICS BUS DATA	1	(60 GHZ COM. LINK)	

*DESIRABLE FOR CERTAIN MULTI-AIRCRAFT TESTS (E.G., FOR COLLISION OR TERRAIN AVOIDANCE OR SCENARIO SIMULATION INFORMATION) and the best known ground reference. See Reference 2 for a detail description and discussion of GPS for DFRF operations.

4.1.5 Vehicle Interface Units

For NRCFRF to be most effective it should have a standard vehicle interface unit (VIU) that provides all the interface between the vehicle and the remote computational stations (DFRF and remote stations). It would be convenient for the VIU to also contain the GPS receiver and the internetting communications link if appropriate. Table 5 lists the type of features needed in the VIU and suggests a standard pod similar to the one the Cubic Corporation builds for air-combat maneuvering (ACM) ranges called the airborne instrumentation subsystem (AIS). See Reference 3 for a discussion of the Cubic System. It is self contained and carried on standard missile launchers so there is minimal installation time required. The various VIU functions could be developed as modules that are selectable depending on the particular tests being done. There would be one digital computer for the pod system functions, such as being the executive controller for the particular suite of modules selected. Table 5 lists the type of modules that should be considered. If more modules are needed than will fit in one pod then two pods would be used with an inter-pod communications link. It may be necessary for some special installation work to be done to arrange for the inter-pod link and for tying into the avionics bus.

TABLE 5.

SUGGESTED FAR-TERM VEHICLE INTERFACE UNIT FEATURES

VEHICLE INTERFACE UNIT (VIU) BETWEEN THE AIRCRAFT AND EXTERNAL SYSTEMS INCLUDING:

- O REMOTE COMPUTATIONAL FACILITIES
- O SPACE POSITIONING SYSTEMS
- O OTHER AIRCRAFT (IF APPROPRIATE)

CONSIDER A STANDARD POD MODULAR DESIGN TO COVER MOST CASES

- O SIMILAR TO CUBIC'S AIS POD FOR ACM INSTRUMENTATION
- O CARRY ON STANDARD MISSILE LAUNCHERS (HELICOPTERS & AIRPLANES)
- O MORE THAN ONE POD COULD BE USED ON AN AIRCRAFT
- O VARIOUS MODULES SELECTABLE FOR ANY GIVEN POD, SUCH AS
  - LOW DATA RATE UP/DOWN LINK (UP TO 200 KBPS) AND ANTENNA
  - MODERATE DATA RATE DOWN LINK (UP TO 1 MBPS) AND ANTENNA
  - HIGH DATA RATE UP/DOWN LINK (UP TO 500 MBPS) AND ANTENNA
  - INTER-AIRCRAFT DATA LINK (INTERNETTING)
  - INTER-POD COMMUNICATIONS (IF MORE THAN ONE POD ON AIRCRAFT)
  - ENCRYPTER/DECRYPTER
  - INERTIAL SENSOR UNIT
  - GPS RECEIVER
  - AIR DATA SENSOR
  - RADAR ALTIMETER
  - SIGNAL CONDITIONING
  - AVIONICS BUS (1553) INTERFACE
  - FLIGHT CONTROL SYSTEM (FCS) INTERFACE
  - DIGITAL COMPUTER FOR POD SYSTEM FUNCTIONS
  - DIGITAL COMPUTER FOR EXPERIMENT COMPUTATIONS
  - OTHER

Two examples of potential NRCFRF flight demonstration activities and various suitable pod modules which might satisfy the particular needs are presented in Table 6. Note that the second example uses two pods on one aircraft with different modules and an inter-pod communication link.

TABLE 6.

EXAMPLES USING FAR-TERM VEHICLE INTERFACE UNITS

1. LEAD AIRCRAFT AND ROBOTIC WINGMAN (RW) DEMONSTRATION AGAINST ONE THREAT AIRCRAFT

RW POD MODULES:

- MODERATE DATA RATE DOWN LINK AND ANTENNA
- LOW DATA RATE UP LINK
- ENCRYPTER/DECRYPTER
- INERTIAL SENSOR UNIT
- GPS RECEIVER
- AIR DATA SENSOR
- SIGNAL CONDITIONING
- FCS INTERFACE
- DIGITAL COMPUTER FOR POD SYSTEM FUNCTIONS

LEAD AND THREAT AIRCRAFT POD MODULES:

- LOW DATA RATE DOWN LINK AND ANTENNA
- ENCRYPTER/DECRYPTER
- GPS RECEIVER
- SIGNAL CONDITIONING
- DIGITAL COMPUTER FOR POD SYSTEM FUNCTIONS

2. SUPERCOCKPIT FLIGHT DEMONSTRATION REQUIRING TWO PODS

POD #1:

- MODERATE DATA RATE DOWN LINK AND ANTENNA
- LOW DATA RATE UP LINK
- ENCRYPTER/DECRYPTER
- INERTIAL SENSOR UNIT
- GPS RECEIVER
- AIR DATA SENSOR
- SIGNAL CONDITIONING
- DIGITAL COMPUTER FOR POD SYSTEM FUNCTIONS
- DIGITAL COMPUTER FOR EXPERIMENT (DISPLAYS) COMPUTATIONS
- INTER-POD COMMUNICATIONS LINK

POD #2:

- HIGH DATA RATE UP/DOWN LINK AND ANTENNA
- ENCRYPTER/DECRYPTER
- DIGITAL COMPUTER FOR EXPERIMENT (VIDEO MIXING) COMPUTATIONS
- INTER-POD COMMUNICATIONS LINK

The standard pod would not work for all aircraft using the NRCFRF. One should consider designing the standard pod modules so that they could be repackaged for internal installation, for example in the NASP. They could also be used for aspects of relay aircraft (see Remote/Mobile Operations Section 4.2.2).

4.1.6 Pilot Vehicle Interface

Having the appropriate pilot vehicle interface (PVI) is critical to virtually any test that would be done using the NRCFRF. Changing the PVI in a flight vehicle can be a costly matter. The NRCFRF ground system data links and vehicle interface unit should be designed to aid the PVI installation problem for many of the simulations. Table 7 suggests several potential PVI systems elements that should be considered. Remote computation can assist on a number of these systems to provide diversity and flexibility in the characteristics of the PVI. When possible, the sensory device, e.g., display screen, projection device in a HUD or HMD, or the handle and buttons on a controller, should be made to interface with a general purpose computer in the standard pod to allow the general information content to be programmable. Some information could be computed on the ground, data-linked to the aircraft, and integrated into the PVI system.

TABLE 7.

SUGGESTED FAR-TERM PILOT-VEHICLE INTERFACE FEATURES

POTENTIAL ADVANCED PILOT VEHICLE INTERFACE (PVI) SYSTEMS TO CONSIDER

- MULTI-FUNCTION CRTs
  - ACCESS TO REPROGRAM DISPLAYS ON EXISTING COCKPIT SYSTEMS
  - INSTALL NEW LARGER SCREEN COLOR CRTS
  - INSTALL COLOR FLAT PANEL DISPLAYS (SMALL SIZE BY MID 1990S, FULL PANEL SIZE BY 2000)
  - USE COMBINATION OF REMOTE AND ONBOARD COMPUTATION
- VOICE INTERACTION SYSTEM
  - MACHINE INTELLIGENCE IN GROUND COMPUTERS
  - USE ADVANCED VOICE UNDERSTANDING ALGORITHMS/HEURISTICS
- HEAD-UP-DISPLAYS (HUD)
  - USE WIDE ANGLE HUD FOR PVI RESEARCH AND TEST ENVIRONMENT SIMULATION (E.G., DISPLAY SIMULATED TARGETS AND THREATS)
  - USE COMBINATION OF REMOTE AND ONBOARD COMPUTATION
- HELMET MOUNTED DISPLAYS (HMD)
  - ACCESS TO REPROGRAM DISPLAY INFORMATION ON HMDS FOR ADVANCED AIRCRAFT (E.G., ATF AND LHX)
  - USE ADVANCED EXPERIMENTAL HMDS FOR PVI RESEARCH AND TEST ENVIRONMENT SIMULATIONS (E.G., DISPLAY SIMULATION SAMS)
  - USE COMBINATION OF REMOTE AND ONBOARD COMPUTATION
- MULTI-FUNCTION PILOT CONTROLLERS
  - ACCESS TO REPROGRAM EXISTING PILOT CONTROLLERS IF POSSIBLE
  - DEVELOP SPECIAL RESEARCH CONTROLLERS
  - USE COMBINATION OF REMOTE AND ONBOARD COMPUTATION
- OTHERS TO CONSIDER
  - 3-D SOUND SYSTEM
  - HOLOGRAPHIC DISPLAYS

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Figure 15 illustrates how remote computation might be used to produce an advanced PVI display well before flight qualified computers are available to do the job onboard. The picture on the lower left is a computer-generated display that would be displayed on a large screen color CRT in an aircraft cockpit. Flight qualified computers are not yet available that could do the complete computer-generated display in the detail required for a situational awareness display. The concept is to decompose the processing task into those features that require the fastest update rate and slowest update rate; assign those computations to the pod computer and ground computer respectively; and then construct a composite picture from the two elements. A special parallel processor would be used on the ground to do the detail features that require the most extensive computations. The pod computer would calculate the "coordinates" of the features which move faster and do other test update calculations. It would also integrate the data to form the composite picture.

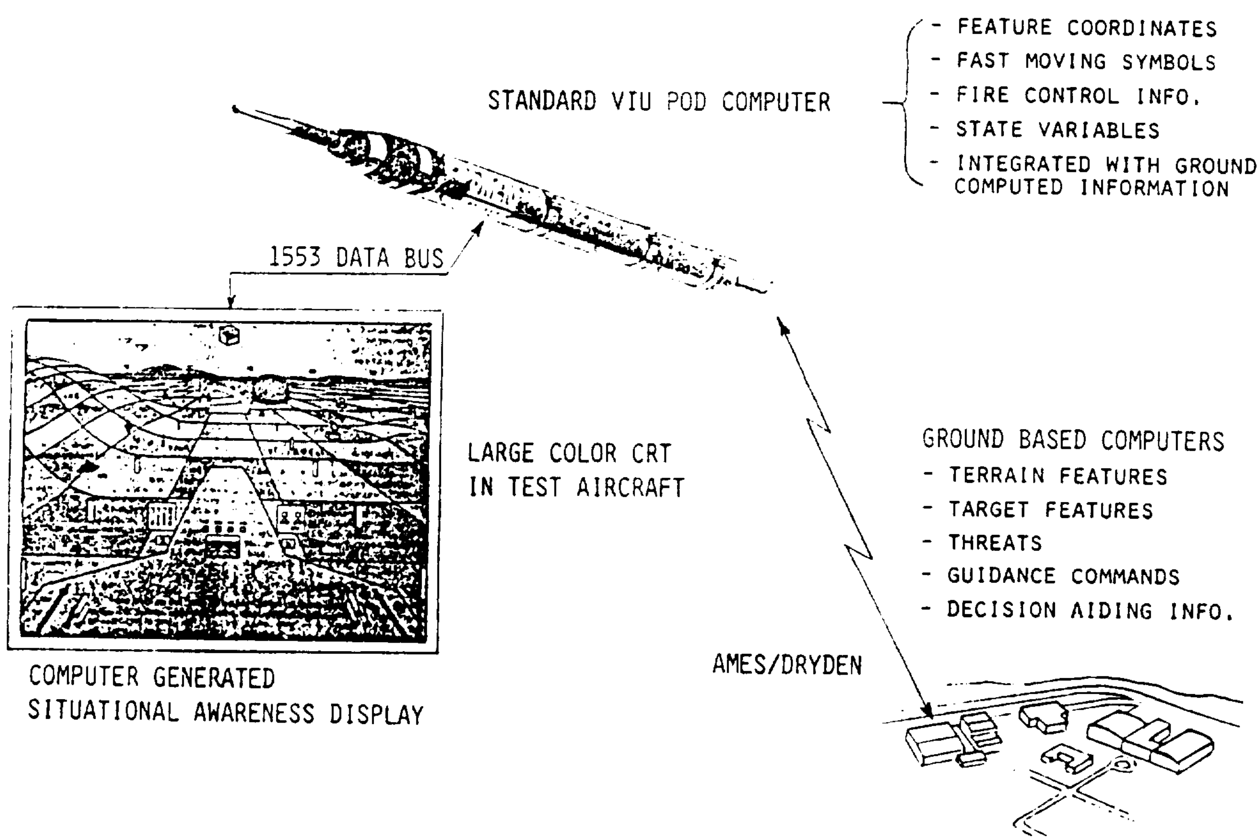

FIGURE 15. EXAMPLE OF REMOTE COMPUTATIONAL SUPPORT FOR PILOT DISPLAYS

4.2 NRCFRF Extended Capabilities

This section discusses several options to extend the capabilities of the baseline facility. These capabilities would be needed for many of the far term programs. The operations and/or functions considered are: multi-aircraft operations; remote/mobile operations; secure systems flight crucial functions; and, extended range operations.

4.2.1 Multi-Aircraft Operations

Table 8 presents an example of multi-aircraft operation tests and the resulting NRCFRF requirements which dictate the range facilities requirements. The example is of military tactical engagement scenario to evaluate PA technology and would be done in cooperation with the military. The intent here is not to suggest that NASA engage in developing or evaluating tactics but rather that the proper tactical situation be established for testing and/or evaluating advanced systems technology that is highly dependent on the operational environment. For example, it would be impossible to get a true evaluation of PA technology which is to offload the pilot in a high workload tactical situation, without creating a realistic tactical situation. Multi-aircraft (M on N) is a very important element of the tactical situation.

Table 9 presents the range and facilities considerations to provide multi-aircraft flight test operations. As discussed previously, GPS augmented by other space positioning data sources in an optimal estimator is ideal for the multi-aircraft operations. It would provide accurate estimates of the velocity and position vectors of all aircraft involved. The down-links should provide full data transfer for up to four experimental aircraft. It would probably be adequate to have one with the highest data rate for advanced displays research. All the aircraft should have at least the low data rate for the GPS data and aircraft state variables. With these data one could predict the future position several seconds ahead, either air-to-air or air-to-ground, for collision avoidance advisories. This would give an added safety margin when evaluating advanced technology under high risk conditions such as multiple helicopters in NOE or air-to-ground combat, or high performance fighters in a coordinated terrain following mission with internetting. Other down-linked data would be used for supporting the test objectives, such as guidance or AI computations, weapons simulation or advanced display information. Up-link data to all the aircraft might be used for collision avoidance advisory or indication that the aircraft has been negated by a simulated weapon hit.

4.2.2 Remote/Mobile Operations

The ability to support tests at remote locations and to have mobility to change test support sites would truly give NRCFRF national importance. It could support tests at other NASA Centers and DOD test ranges or move to remote areas of the desert

TABLE 8.

MULTI-AIRCRAFT OPERATIONS EXAMPLE (FAR-TERM)

EXAMPLE OPERATIONS	AIRCRAFT INVOLVED	NRCFRF REQUIREMENTS
DEMONSTRATION OF PILOT'S ASSOCIATE TECHNOLOGY IN A REALISTIC M ON N COMBAT ENVIRONMENT TECHNOLOGIES DEMONSTRATED O TACTICAL DECISION AIDING O THREAT ASSESSMENT O MISSION RE-PLANNING O SITUATION ASSESSMENT ENVIRONMENT REQUIRED O M(>2) FRIENDLY AIRCRAFT O N(>2) BOGIES O REALISTIC WEAPONS O GROUND TARGETS MISSION O SIMULATED STRIKE GROUP O OTHERS	ONE TEST AIRCRAFT O BLUE FLIGHT LEADER O PILOT'S ASSOCIATE SYSTEM (REMOTE) O ADVANCED PILOT-VEHICLE INTERFACE SYSTEM	FULL REMOTE COMPUTATION SYSTEM SUPPORT INCLUDING: O INTEGRATED PA SYSTEM - TACTICAL DECISION ES - THREAT ASSESSMENT ES - MISSION RE-PLANNING ES - SITUATION ASSESSMENT ES O INTELLIGENT VOICE INTERFACE O DISPLAY GENERATION O WEAPONS SIMULATION O FLIGHT SAFETY SUPPORT SPACE POSITIONING TEST SUPPORT
	2 OR MORE OTHER BLUE AIRCRAFT O PROVIDE REALISTIC STRIKE GROUP	SPACE POSITIONING DATA LINKS BATTLE SIMULATION INTERFACE SCORING SYSTEM INTERFACE FLIGHT SAFETY SUPPORT
	3 OR MORE RED AIRCRAFT O PROVIDE REALISTIC THREAT	

TABLE 9.

MULTI-AIRCRAFT SYSTEM CONSIDERATIONS

SPACE POSITIONING

- O GPS IS IDEAL FOR PRECISE MULTI-AIRCRAFT SPACE POSITIONING
- O USE DATA LINK TO PROVIDE POSITION INFORMATION TO GROUND FACILITY
- O GPS DATA CAN BE AUGMENTED IF NECESSARY BY
  - ONBOARD INS OR GROUND COMPUTED "INS" FROM TELEMETRY DATA
  - RADAR ALTIMETER
  - GROUND RADAR TRACKING
  - INTERNETTING FOR RELATIVE POSITIONS (IF USED)

DOWN-LINKS

- O PROVIDE THE FOLLOWING DOWN-LINKS SIMULTANEOUSLY:
  - MODERATE DATA RATE LINKS FOR FOUR AIRCRAFT
  - LOW DATA RATE LINKS FOR UP TO 8 AIRCRAFT
  - HIGH DATA RATE LINK FOR ONE AIRCRAFT

UP-LINKS

- O PROVIDE THE FOLLOWING UP-LINKS SIMULTANEOUSLY:
  - LOW DATA RATE LINKS FOR FOUR AIRCRAFT
  - SHOULD CONSIDER COST AND POTENTIAL BENEFITS FOR HAVING UP-LINKS FOR UP TO 8 OTHER AIRCRAFT
  - HIGH DATA RATE LINK (VIDEO) FOR ONE AIRCRAFT

INTERNETTING

- O CONSIDER PROVIDING INTERNETTING FOR FOUR TO EIGHT AIRCRAFT to support highly classified programs and yet have nearly full remote computational capability. The type of support functions that would be needed in a remote/mobile facility include: data relay to and from DFRF; some local computational support; pre-processing data relayed to DFRF; test monitoring and control; and, integration of real-time processed data from DFRF with locally processed data for up-linking to the local test aircraft.

Three types of mobile remote ground units (MRGU) should be considered as indicated in Table 10. A modular approach would be used so that additional capability could be evolved as needed. The basic MRGU would support remote site operation flight tests of a conventional nature as well as minimal local remote computational support. The baseline MRGU would provide remote computational support similar to that at DFRF only not quite as extensive. For example, it would have data links to and from only one aircraft. MRGUs would probably be in size somewhere between a large motor home and a semi-truck trailer. Some could have their own power generator. The lower portion of Table 10 indicates how multiple MRGUs could be used for multi-aircraft and flight crucial operations. Three or four MRGUs would be needed.

The other element needed for remote operations is a remote airborne platform (RAP). At a minimum, it could be a data relay platform from the test aircraft to DFRF or MRGUs, or from MRGUs to DFRF. One should also consider adding remote computational support onboard the RAP. RAP flying over a test range would have the advantage of no terrain blocking of the signals.

The two aircraft considered in Reference 2 for data relay only NASA ER-2 and the Joint Agency Advanced Range Instrumentation Aircraft (ARIA) would be viable candidates for RAP. The ER-2 could serve as a relay aircraft but has limited volume for extra computers and logic processors. Also, computers used on the ER-2 would probably have to be fully flight qualified. ARIA would be more desirable from several standpoints. The ten foot diameter radar dome would allow a six- to eight-foot diameter antenna for the data link to get a 400 nautical mile range. The large environmentally controlled cargo area would accommodate several mini-computers and logic processors which would not have to be flight qualified. Another option for data relay would be to have data links from mobile earth stations to the NISDN satellite network and then relayed to DFRF.

4.2.3 Secure Systems Considerations

Secure data links and communications are being required at all military bases so encryption will be standard. DOD currently has mobile command and control units that are Tempest qualified; therefore, one can assume that MRGUs can be Tempest qualified. Qualifying RAP would certainly be no more difficult than reconnaissance aircraft which handle highly classified data.

It is not clear whether secure operations would have to be conducted out of the DFRF facility if MRGUs and RAP are

TABLE 10.

REMOTE/MOBILE SYSTEM CONSIDERATIONS

MOBILE REMOTE GROUND UNITS (MRGU)

- o THREE TYPES OF MRGUs SHOULD BE CONSIDERED
  - BASIC FLIGHT TEST SUPPORT MRGU
    - SELF CONTAINED TEST AND EXPERIMENT MONITORING CAPABILITY
    - INTERFACE AND SUPPORT FOR STANDARD VIU PODS (LOW DATA RATES ONLY)
    - MINI-COMPUTERS FOR FLIGHT TEST AND SAFETY SUPPORT
    - COMMUNICATION LINKS TO OTHER MRGUS
    - POSSIBLY A PSEUDO GPS "SATELLITE"
  - BASELINE NRCFRF MRGU: BASIC MRGU PLUS
    - LOW, MODERATE AND HIGH DATA RATE LINKS (ONE AIRCRAFT)
    - FULL LOCAL PROCESSING SUPPORT (ADD LOGIC PROCESSORS AND IMAGE/GRAPHICS PROCESSORS)
    - HIGH DATA RATE LINKS WITH DRYDEN (RELAY MAY BE NEEDED)
  - SECURE MRGU
    - PROVIDE SCIF MRGU (BASIC OR BASELINE) INCLUDING DATA AND VOICE COMMUNICATIONS AND PROCESSING
  - USE MODULAR APPROACH FOR BUILDING MRGUs WITH VARIOUS LEVELS OF CAPABILITIES AND SECURITY REQUIREMENTS
  - PROVIDE CAPABILITY FOR USING SOME MRGUs IN A REDUNDANT CONFIGURATION FOR FLIGHT CRUCIAL OPERATIONS
  - CONSIDER POTENTIAL REQUIREMENTS FOR MRGUs BEING TRANSPORTED BY AIR OR USED ON SHIPS

- o FOR MULTI-AIRCRAFT OPERATIONS
  - USE MULTIPLE MRGUs - ONE FOR EACH AIRCRAFT
  - ONE BASELINE MRGU ALSO SERVES AS COMMAND/CONTROL CENTER
  - MRGUs COULD BE USED TOGETHER WITH PRIMARY CENTER AT DRYDEN FOR MULTI-AIRCRAFT OPERATIONS IN GENERAL (I.E., NON-REMOTE)

- o FOR FLIGHT CRUCIAL OPERATIONS (CANDIDATE CONCEPT)
  - USE MULTIPLE (2 OR 3) MRGUs IN REDUNDANT CONFIGURATION TO SUPPORT ONE AIRCRAFT
  - USE MULTIPLE STANDARD VIU PODS (2 OR 3) AND/OR CUSTOM VIUs
  - REDUNDANCY MANAGEMENT PERFORMED IN MRGUs AND VIUs
  - SEPARATE MRGU USED FOR TEST MONITORING, COMMAND AND CONTROL

REMOTE AIRBORNE PLATFORM (RAP)

- o TWO TYPES OF RAPs SHOULD BE CONSIDERED
  - RELAY AIRCRAFT (I.E., MODIFIED ARIA OR ER-2 RELAY AIRCRAFT DEFINED IN VERAC REPORT REF. 1)
  - RELAY AIRCRAFT PLUS REMOTE COMPUTATIONAL PLATFORM
    - CAPABILITIES SIMILAR TO MRGUS
    - USE SAME MODULES AS MRGUS IN CABIN ENVIRONMENT
- o ON HIGH PRIORITY PROGRAMS (I.E., NASP) MAY WANT TO CONSIDER MORE THAN ONE RAP

Tempest qualified. It may be preferable to keep the secure operations at remote areas. In any case, encrypted communications and data links would be available to the DFRF facility as well as the MRGUs.

4.2.4 Flight Crucial Functions

Three examples of potential flight crucial functions that might be conducted using the NRCFRF are indicated on Figure 16 together with suggested integrity requirements and potential remote systems concept requirements. The first involves flying a robotic aircraft in close proximity to a manned aircraft, similar to an operational RW, i.e., no safety pilot. The integrity requirement is for the robotic aircraft being operated via remote computation to demonstrate the concept. The requirements could be met with dual redundant MRGUs and an onboard logic and control system that would always command the robotic aircraft away from the manned aircraft and then be operated with a backup RPV mode from a third MRGU or directly from DFRF.

EXAMPLE FUNCTIONS	INTEGRITY REQUIREMENTS			POTENTIAL REMOTE SYSTEM CONCEPT
	1st FAILURE	2nd FAILURE	3rd FAILURE	
OPERATION OF A ROBOTIC AIRCRAFT NEAR A MANNED AIRCRAFT	NO CATASTROPHIC MANEUVERS PLUS ABORT TEST, RETURN HOME AND LAND	NO CATASTROPHIC MANEUVERS PLUS SAFE RECOVERY CAPABILITY	LOSS OF ROBOTIC AIRCRAFT	o ALL CRITICAL ELEMENTS DUAL (MAY BE DISSIMILAR) o REVERSION TO ONBOARD RETURN MODE o BACKUP RPV MODE(s)
AUTOMATED NOE OPERATIONS	FAIL OPERATIONAL PLUS ABORT TEST AND REVERT TO MANUAL MODE	FAIL SAFE PLUS AUTOMATIC REVERSION TO MANUAL MODE	NO CATASTROPHIC MANEUVERS PLUS SAFE RECOVERY CAPABILITY	o ALL CRITICAL ELEMENTS TRIPLEX (MAY BE DISSIMILAR) o REVERSION TO MANUAL MODE
TERRAIN FOLLOWING/ AVOIDANCE	FAIL OPERATIONAL PLUS ABORT TEST AND REVERT TO MANUAL MODE	FAIL SAFE PLUS AUTOMATIC REVERSION TO MANUAL MODE	NO CATASTROPHIC MANEUVERS PLUS SAFE RECOVERY CAPABILITY	o ALL CRITICAL ELEMENTS TRIPLEX (MAY BE DISSIMILAR) o REVERSION TO MANUAL MODE

FIGURE 16. EXAMPLES OF FLIGHT CRUCIAL FUNCTIONS

Automated NOE, and terrain following and avoidance are flight crucial because of the close proximity to the ground and obstacles. These require triplex MRGUs to assure fail/operational capability.

A substantial design study and reliability analysis would be necessary to determine whether these are feasible using remote computation. Flight tests involving remote computation via data-links as part of a flight crucial system would have to be considered on a case-by-case basis. Integrity requirements vary depending on the vehicle/systems and test conditions, e.g., back-up systems with a safety pilot tend to lessen fault tolerance requirements of the primary system. The interface between the aircraft flight crucial elements and the remote elements would generally be different in each case. In general, some increased risk is more likely with the remote computation than a totally onboard system

All flight-crucial remote system elements should be dedicated and separate from non crucial functions. Any interface must be designed to preclude critical faults from propagating into the flight crucial elements. Even if it is not clear whether flight crucial functions will be performed with NRCFRF, it would be wise to consider these requirements when designing and planning NRCFRF and incorporate provisions for it if reasonable. The modular design approach discussed here could make it more practical. Two potential implementation concepts are illustrated in Figures 17 and 18.

Concept 1 (Figure 17) is a dedicated triplex system at DFRF with three separate data link channels, three separate space positioning data sources and three separate channels of processing. The aircraft would also have to have 3 VIUs with appropriate triplex interface with the aircraft flight crucial system(s). One of several possible redundancy management approaches could be considered. The flight crucial interface system would allow data from the non-crucial portion of the system to be used, yet inhibit propagation of faults into the crucial elements.

Concept 2 (Figure 18) uses three dedicated MRGUs, one for each channel. Redundancy management among the MRGUs could be via radiated or cable data links. An alternate to this concept would be to substitute DFRF for one of the MRGUs.

In each case, the airborne portion of the system could be accomplished with three standard pods, one for each channel. A fourth would be used for non-crucial functions.

4.2.5 Extended Range Operations

The range of the NRCFRF could be extended to cover any portion of the United States and other parts of the world, if needed, through a relay system including the Tracking and Data Relay Satellite System (TDRSS) or NISDN satellite network. Figure 19 illustrates the extended range capability using a MRGU, RAP, and TDRS to relay back to DFRF. In such a case, one would divide the computational task into three parts: (1) fast update rate computations would be done onboard the test aircraft in the standard pod; (2) medium update rate computations could be done in the MRGU and/or RAP; and, (3) slower update rate computations would be done at the primary computation center at DFRF. It would be treated as a distributed processing system with multiple sampling rates.

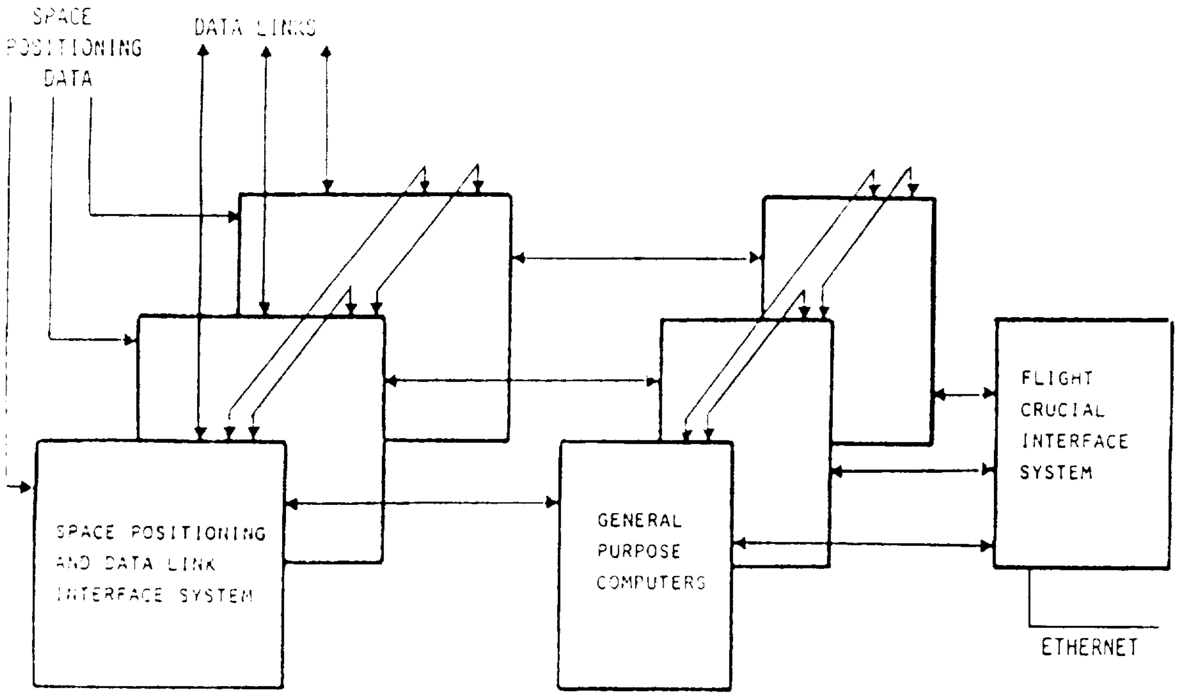

FIGURE 17. POTENTIAL REDUNDANT REMOTE COMPUTATIONAL SYSTEM FOR FLIGHT CRUCIAL FUNCTIONS: CONCEPT 1 DEDICATED SYSTEM AT DFRF

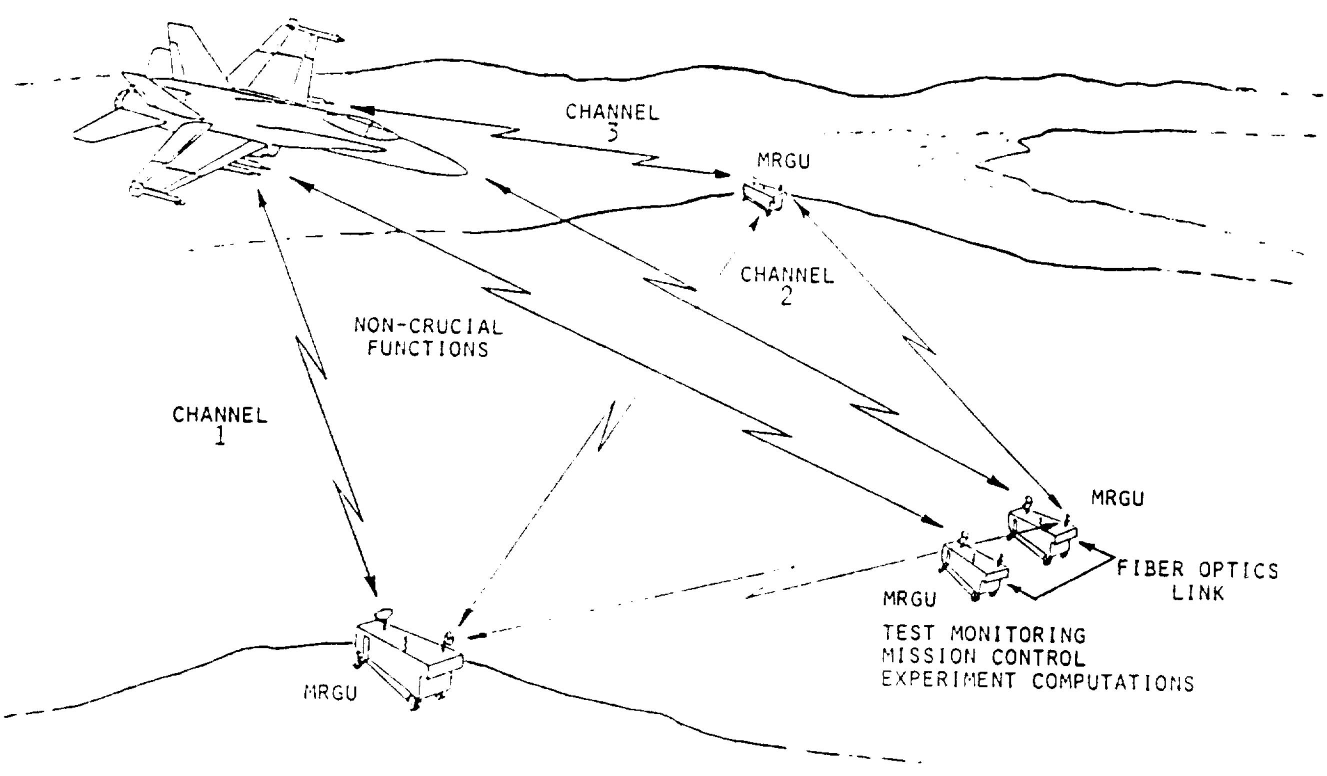

FIGURE 18. POTENTIAL REDUNDANT REMOTE COMPUTATIONAL SYSTEM FOR FLIGHT CRUCIAL FUNCTIONS: CONCEPT 2 DEDICATED MRGUs

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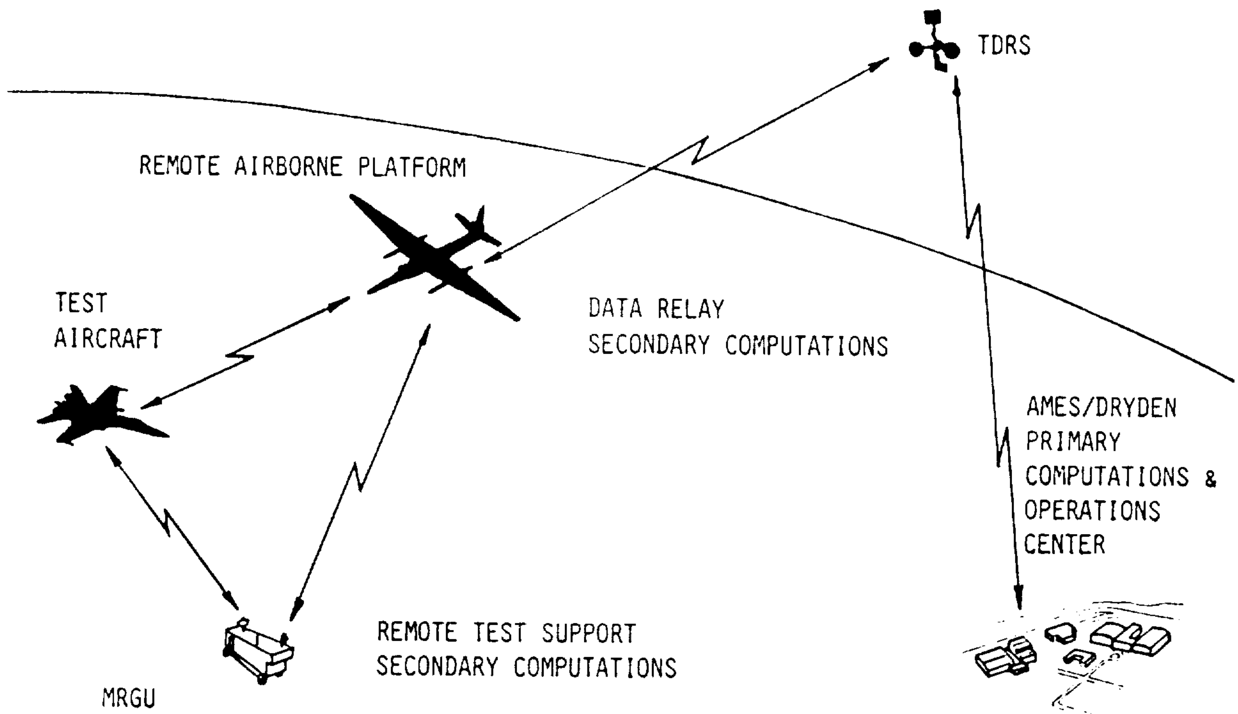

FIGURE 19. EXTENDED RANGE CONCEPT VIA DATA RELAYS

Figures 20 and 21 illustrate how NRCFRF might be used to support NASP flight tests over extended ranges. The ground tracks and energy management footprints are illustrative only. The first example is a suborbital tests over the continental USA with a maximum Mach number of 10 involving 3 MRGUs and one RAP. These would provide good experiment coverage throughout the nominal flight path, but would not necessarily cover all emergency conditions.

The second example, Figure 21, illustrates coverage potential for an orbital mission using 3 MRGUs and one RAP that first covers the ascent then moves west to cover the descent. There would have to be at least 7 orbits to allow RAP to move to the new position. It only provides limited coverage of the energy management footprint up to about M=10. In both of these examples, it would be necessary to use more MRGUs and RAPs to cover the energy management function totally or use direct data links from NASP to TDRS to DFRF if that is possible.

4.3 Suggested Facilities Development Schedule

A suggested development schedule for the various facilities discussed is presented in Figures 22 through 26. This development schedule is timed to provide necessary capabilities to do the near- and far-term programs identified earlier and phased such that the systems and facilities could be evolved in a practical and fiscally responsible manner.

NASP HORIZONTAL TAKEOFF AND LANDING AT EDWARDS
MAX MACH NUMBER OF 10 AT 100,000 FT. ALTITUDE

- o THREE MRGUs (♦) WITH 150 NM RANGE
- o ONE RAP (✦) WITH 400 NM RANGE

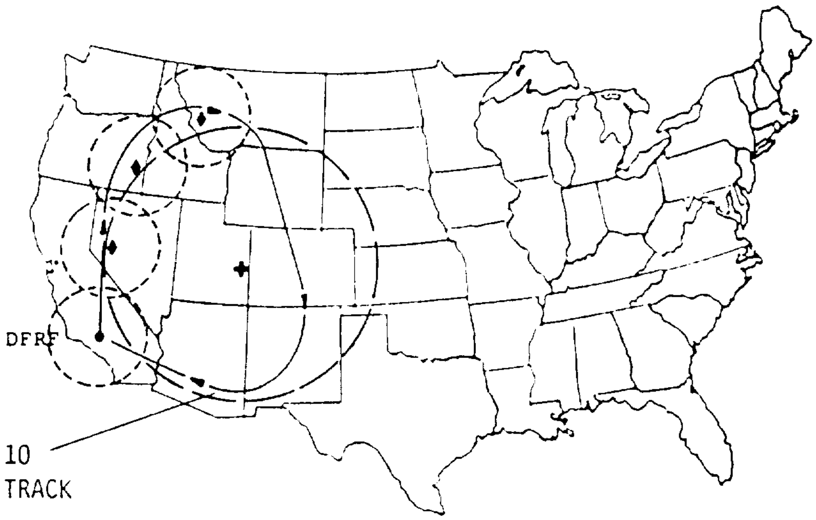

FIGURE 20. EXTENDED RANGE COVERAGE FOR NASP: MACH 10 TEST EXAMPLE

NASP HORIZONTAL TAKEOFF, ACCELERATING ASCENT TO ORBIT, MULTIPLE ORBITS, DECELERATING DESCENT FROM ORBIT AND HORIZONTAL LANDING AT EDWARDS

- o THREE MRGUs (♦) WITH 150 NM RANGE
- o ONE RAP (✦) WITH 400 NM RANGE (MOVES TO COVER ASCENT AND DESCENT)

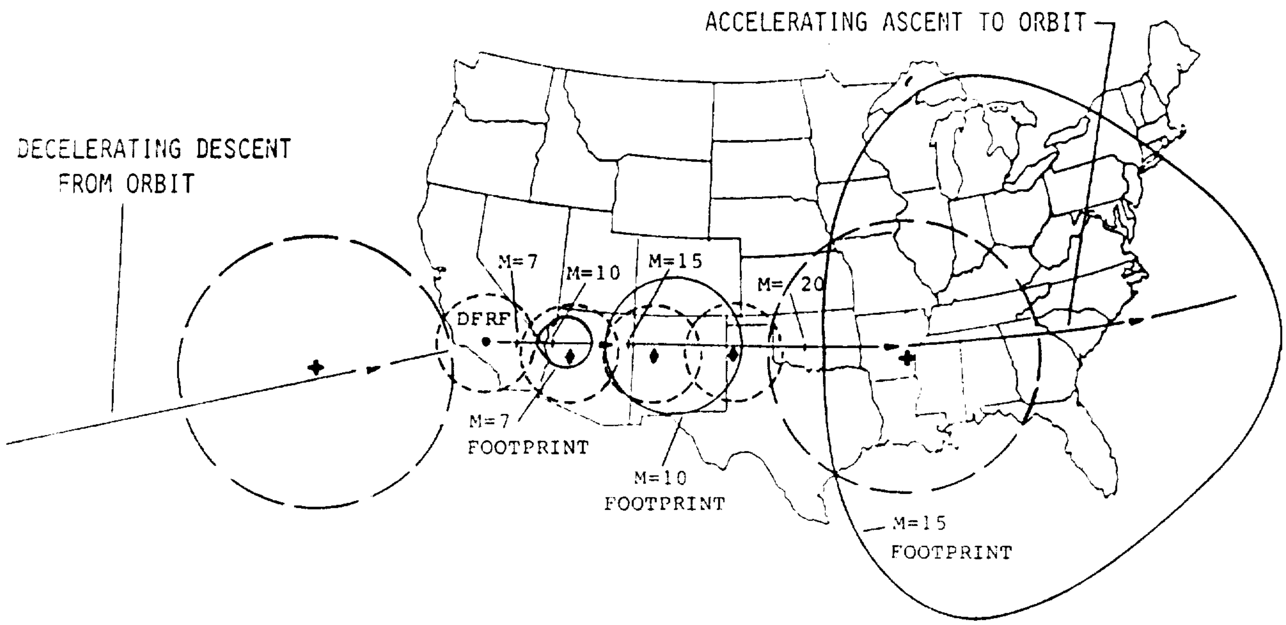

FIGURE 21. EXTENDED RANGE COVERAGE FOR NASP: ORBITAL MISSION EXAMPLE

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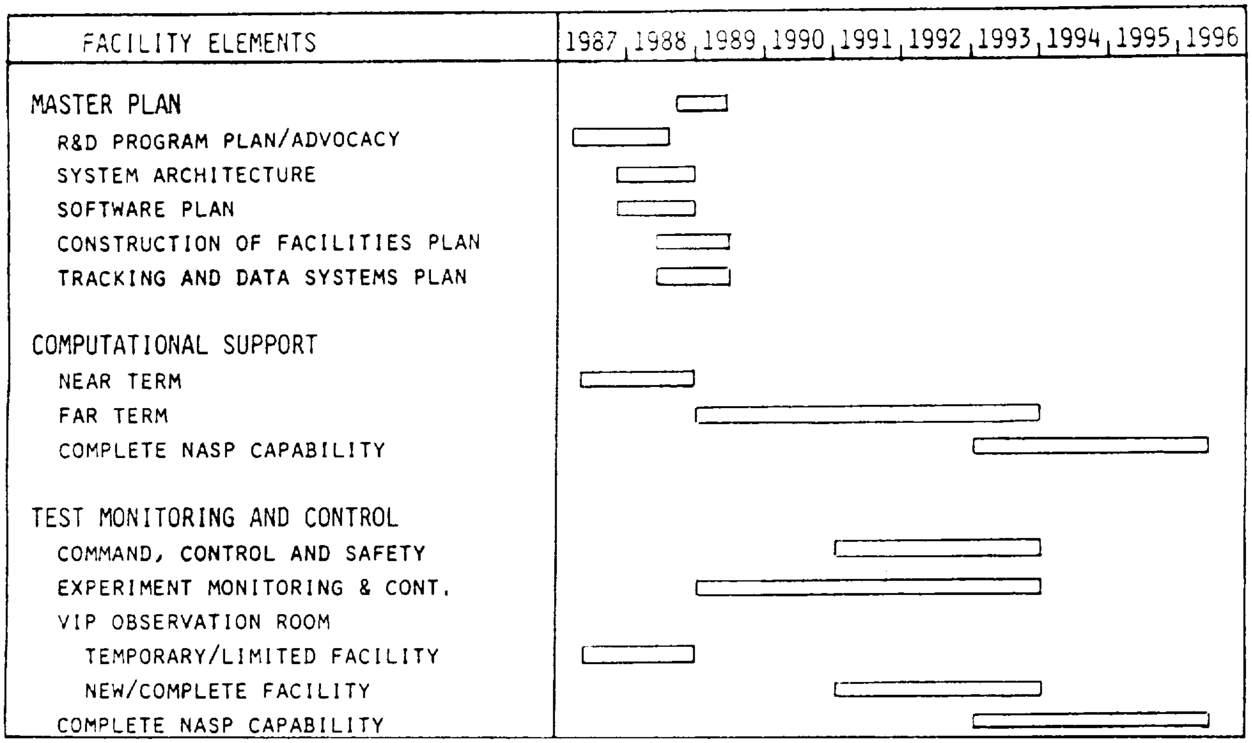

FIGURE 22. SUGGESTED FACILITIES DEVELOPMENT SCHEDULE

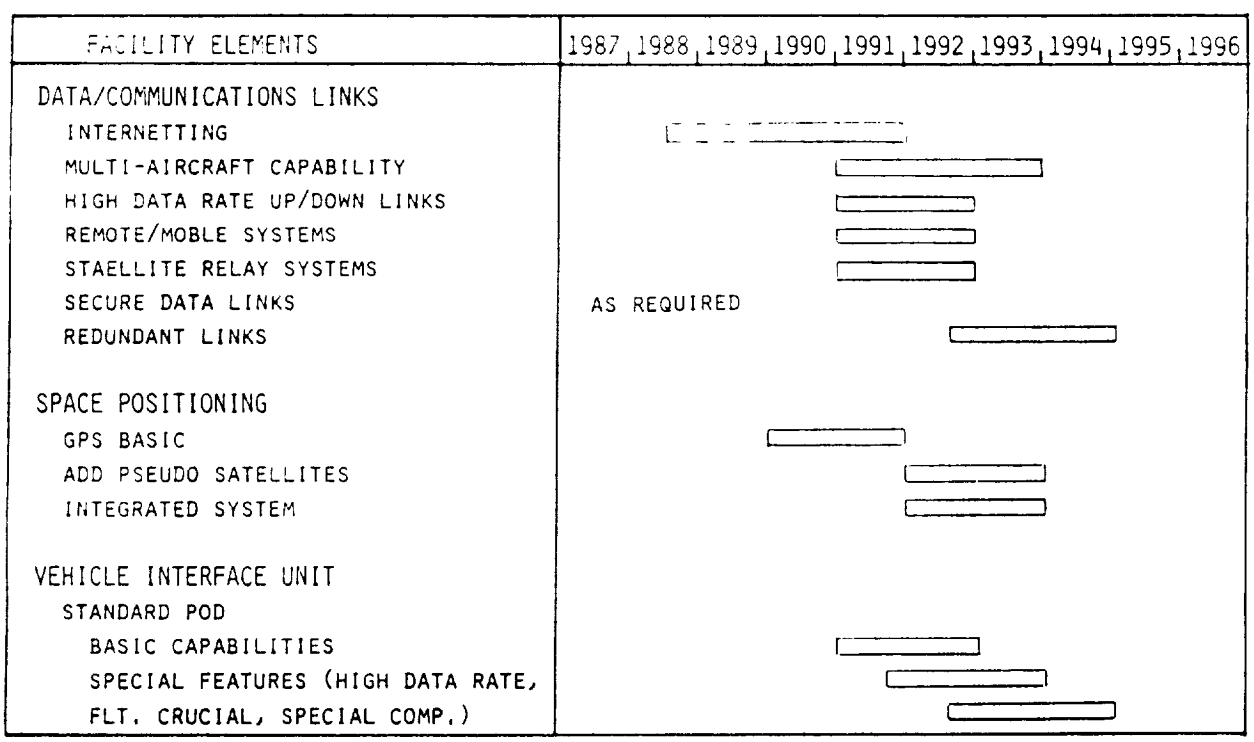

FIGURE 23. SUGGESTED FACILITIES DEVELOPMENT SCHEDULE (cont'd)

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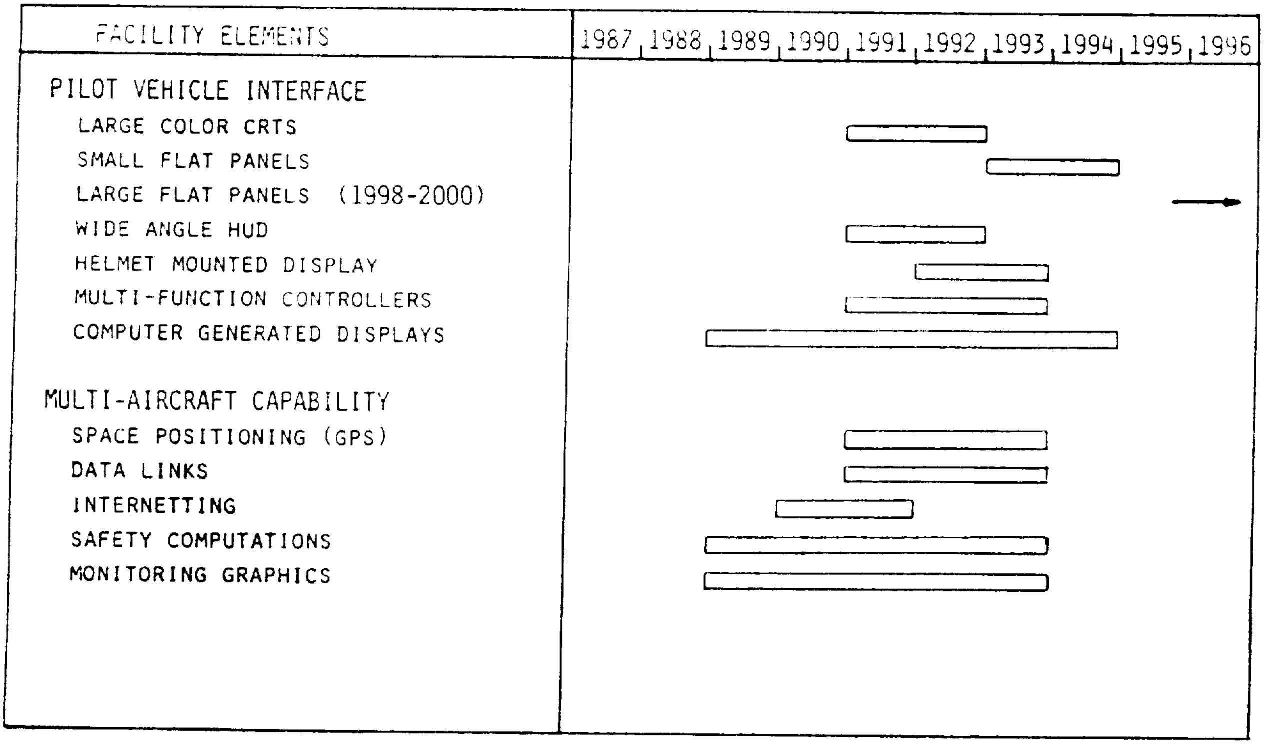

FIGURE 24. SUGGESTED FACILITIES DEVELOPMENT SCHEDULE (cont'd)

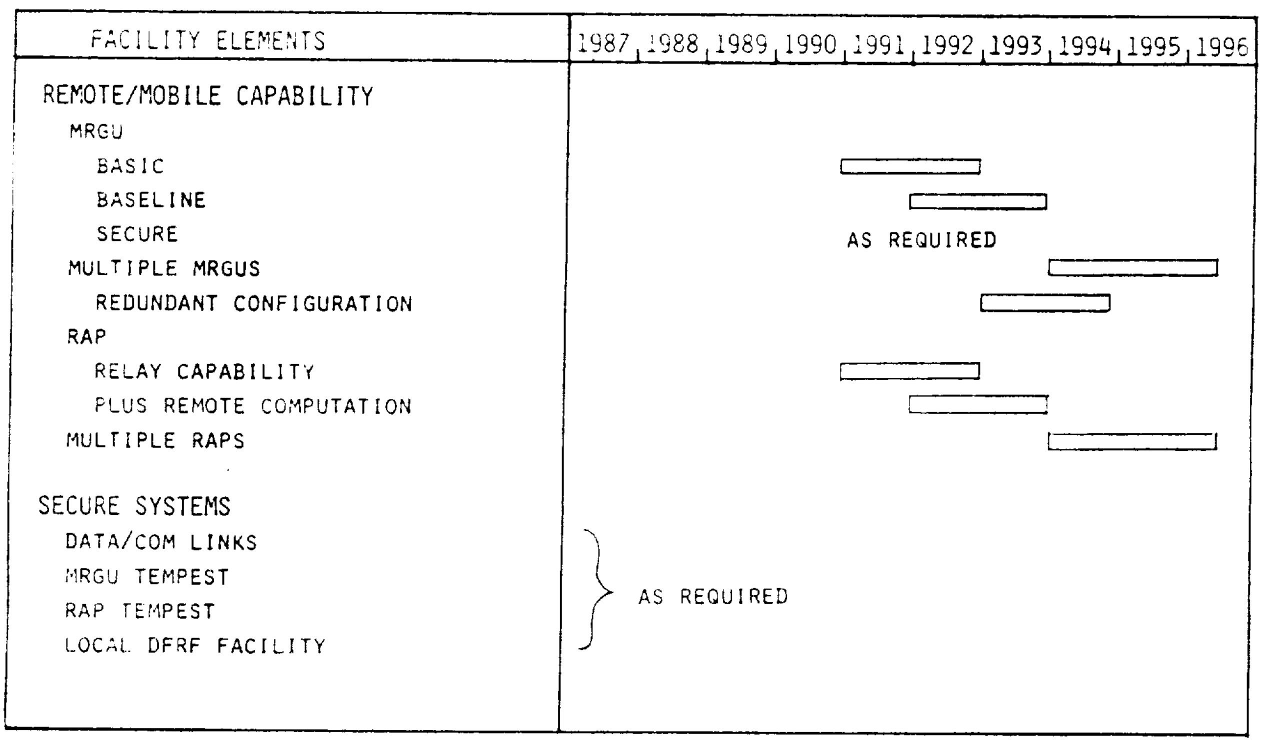

FIGURE 25. SUGGESTED FACILITIES DEVELOPMENT SCHEDULE (cont'd)

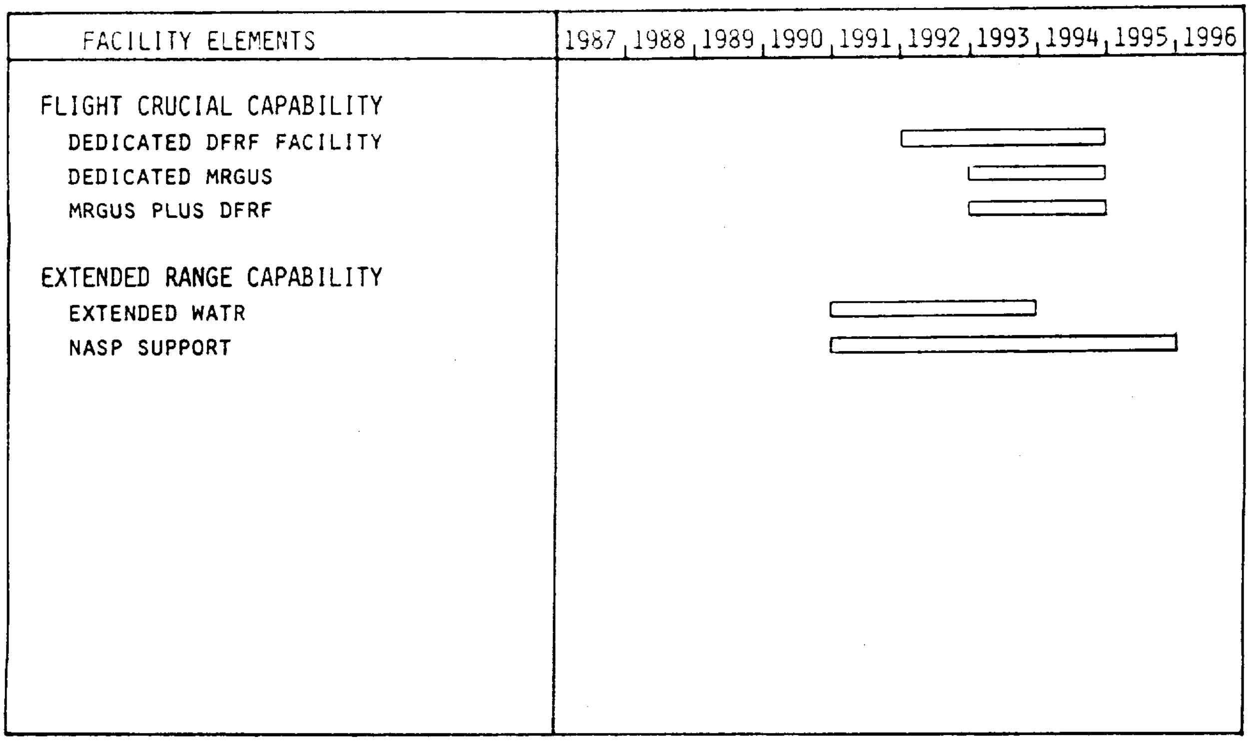

FIGURE 26. SUGGESTED FACILITIES DEVELOPMENT SCHEDULE (concluded)

The first item is to develop a Master Plan. This report could be a starting point for the Master Plan. The R&D program plan and advocacy package establishes the justification for developing NRCFRF. It would also have to contain a proposed testing methods development budget plan. A substantial R&D investment over the next ten years would be needed to develop the testing concepts and application software for NRCFRF, such as real-time experiment support algorithms. Certain elements of the system would probably have to be developed by specific R&D programs rather than developing a generic capability. For example, a "Big Picture" display cockpit would probably be part of a specific R&D program. However, once developed, it could be used as a generic display for PVI research. It is important to establish an overall system architecture that would encompass the "Baseline Facility" and "Extended Capabilities" so that NRCFRF can evolve over an eight to ten year period as the various capabilities are needed. Large amounts of software will have to be developed during that time. A well thought out software plan that is compatible with the system architecture will be necessary to make the job tractable and affordable. The Master Plan would integrate the R&D Plan, Construction of Facilities Plan, and the Tracking and Data Systems Plan.

The near-term developments starting in 1987 for computational support and test monitoring and control relate to the Robotic Wingman program. 1993 is the approximate time period when much of the far term capabilities would be needed; therefore, most of the elements are phased to be completed by that time. The modular and evolutionary approach allows a build up to the full capability so that portions of the system could be used throughout the development period. The full capability needed to support NASP would not have to be ready, checked out, and validated until mid-1996.

4.4 Relationship to Other Ranges

This section discusses the relationship NRCFRF would have to various DOD test and training ranges. The following ranges were visited and their facilities reviewed: Nellis Air Force Base in Las Vegas, Nevada; Naval Air Station in Fallon, Nevada; Naval Weapons Center in China Lake, California; Fort Hunter-Leggett/Fort Ord, California; and, the Naval Air Test Center, Patuxent River, Maryland. Summaries of the reviews are presented in Tables 11 through 15.

The compatibility of these existing DOD ranges and NRCFRF, additional requirements that would have to be placed on NRCFRF to operate with these ranges and assessments as to the relative merit of possibly operating with them are outlined in Table 16. In general, it would be possible for NRCFRF to be compatible with all these DOD ranges. The charters and heavy training schedules at Nellis and Fallon make joint operation very difficult and unlikely. It would definitely be worth discussing potential collaborative efforts and facilities compatibility with the Naval Weapons Center, Fort Hunter-Leggett/Fort Ord and the Naval Air Test Center. NRCFRF with the extended range capability could augment each of these ranges if steps are taken to assure compatibility.

NRCFRF would clearly be unique in the country from the standpoint of charter, capabilities, and ability to support DOD and NASP. Tables 17 through 20 address each aspect of uniqueness respectively. NRCFRF would truly be a unique National resource.

TABLE 11.

FLIGHT TEST RANGE AND FACILITIES REVIEW:
NELLIS AFB, LAS VEGAS, NV

THE NELLIS RANGE COMPLEX SERVES AS A COMBAT TRAINING DEVICE WITH EMPHASIS ON TACTICS, POSITIONING AND KILL PROBABILITY. IT IS NOT A TEST RANGE.

CAPABILITIES:

- LARGE SCALE MOCK BATTLE STAGING
  - UP TO SEVERAL HUNDRED AIRCRAFT
  - OVER 20 DIFFERENT AIRCRAFT TYPES
  - OVER 4500 SORTIES
  - 1400 TARGETS
  - ELECTRONIC GROUND THREAT SIMULATORS
- 50 SIMULTANEOUS WEAPONS SIMULATIONS
- 36 SIMULTANEOUS BOMB SIMULATIONS WITH UP TO 22 BOMBS PER AIRCRAFT
- REAL-TIME VIDEO FOR DISPLAY/REPLAY

RANGE FEATURES:

- EXTENDS 100 MILES AT 500 FT. ALTITUDE (60 MILES @ 100 FT.)
- GROUND STATION - SINGLE RADAR TRACKER AND 18 REPEATER STATIONS (2 SETS OF 9 BASIC STATIONS)
- TRACKING ACCURACY 25 FT. @ HIGH ALTITUDES, 50 FT. @ LOW ALTITUDES

TABLE 12.

FLIGHT TEST RANGE AND FACILITIES REVIEW:
NAVAL AIR STATION, FALLON, NV

THE NAS PRIMARILY SUPPORTS THE TACTICAL TRAINING OF AIR WINGS AND TYPICALLY TRAINING IS CONDUCTED JUST PRIOR TO AN AIR WING JOINING A CARRIER FOR A TOUR OF SEA DUTY. APPROPRIATE TACTICS FOR A PARTICULAR THEATRE ARE DEVELOPED AND THE NEARBY MOUNTAINS USED TO EXPLORE TERRAIN-MASKING TECHNIQUES. NOT A TEST RANGE.

CAPABILITIES:

- RANGE SYSTEM IS USED STRICTLY FOR TRACKING WITH DATA RECORDED ON TAPE FOR REAL-TIME DISPLAY OR REPLAY AS PART OF THE DEBRIEFING PROCESS
- SUPPORT FULL DATA FROM 36 AIRCRAFT SIMULTANEOUSLY
- PERFORM 50 SIMULTANEOUS WEAPONS TRAJECTORY CALCULATIONS
- FACILITIES INCLUDE 4 BOMBING, 2 STRAFING, AND 1 ELECTRONIC WARFARE RANGE
- SECURE VOICE COMMUNICATIONS

RANGE FEATURES:

- CONTROLS APPROXIMATELY 6,000 SQUARE MILES OF AIRSPACE (EXPECT 10,000 END OF '87)
- 7 GROUND STATIONS (TO ADD 10 MORE)
- RANGE ACCURACY 25 FT X, Y; 50 FT. Z DOWN TO 11,000 MSL

TABLE 13.

FLIGHT TEST RANGE AND FACILITIES REVIEW:
NAVAL WEAPONS CENTER, CHINA LAKE, CA

THE NWC IS A MAJOR RESEARCH, DEVELOPMENT, TEST AND EVALUATION FACILITY FOR AIR WARFARE SYSTEMS. IT IS THE NAVY'S PRIMARY CENTER FOR MISSILE WEAPON SYSTEMS DEVELOPMENT AND HOUSES VARIOUS RANGE FACILITIES FOR TESTING AIR-TO-AIR AND AIR-TO-GROUND ORDNANCE.

TEST RANGES/FACILITIES:

- AIR OPERATIONS - GUIDED WEAPONS, BOMBS, FIRE CONTROL SYSTEMS AND AIR-TO-GROUND MISSILES
- MISSILE FIRING - GUIDED AND SMALL MISSILES
- MISSILE BALLISTIC - GROUND-TO-GROUND BALLISTIC AND GUIDED MISSILE PROJECTILES, GROUND LAUNCHED ROCKETS
- SUPERSONIC TEST TRACKS - 4.1 MILE RESEARCH TRACK, 3,000 FT. TERMINAL AND EXTERIOR BALLISTIC TRACK
- AIRCRAFT SURVIVABILITY - TEST AIRCRAFT ENGINES AND SYSTEMS TO ASSESS WEAPON DAMAGE
- ELECTRO-OPTICAL FIELD - LASER DEVELOPMENT AND SENSOR EVALUATION
- RADAR CORSS SECTION - MEASURE CROSS SECTION OF FLYING AIRCRAFT AND MISSILES
- RADIO FREQUENCY MEASUREMENT FACILITY - ANEODIC CHANBERS AND OUTDOOR ANTENNA RANGE TO TEST RF DEVICES
- PROPULSION AND SOLID ROCKET MOTOR TEST FACILITY - TEST AIR-BREATHING PROPULSION AND ROCKET MOTOR SYSTEMS
- ECHO FACILITY - ELECTRONIC WARFARE THREAT ENVIRONMENT SIMULATIONS (EWTES) TO SIMULATE SOVIET LAND AND SEA-BASED RADAR SYSTEMS
- PARACHUTE TEST AND EVALUATION - MAIN CENTER FOR EJECTION SEAT AND PARACHUTE RDT&E
- OUTDOOR FUZE AND SENSOR TEST FACILITY - FUZE AND SENSOR TESTS INCLUDING AIRCRAFT FLY-BYS
- OTHERS - ISOLATED RANGES FOR EXPLOSIVES AND ORDNANCE ENVIRONMENTAL TESTS

CAPABILITIES AND INSTRUMENTATION:

- FULL- AND SUB-SCALE DRONE OPERATIONS (TO DEVELOP DRONE FORMATION FLIGHT SYSTEMS)
- RADARS, TELEMETRY AND LASER TRACKING
- VIDEO SYSTEM FOR TRACKING, SCORING, RECORDING STOPPED MOTION
- VIDEO THEODOLITE, MISS DISTANCE SYSTEM AND VELOCITY MEASUREMENT
- INTEGRATED TARGET CONTROL SYSTEM (ITCS) - HIGH RELIABILITY DATA LINK, 250 MILE SYSTEM
- GROUND COCKPIT - T-38 PROCEDURES TRAINER MODIFIED FOR RPV COCKPIT

RANGE FEATURES:

- COVERS OVER 1,800 SQUARE MILES
- CONTROLS OVER 17,000 SQUARE MILES OF AIRSPACE (12% OF CALIFORNIA AIRSPACE)

TABLE 14.

FLIGHT TEST RANGE AND FACILITIES REVIEW: FORT HUNTER-LEGGETT/FORT ORD, CA

THIS U.S. ARMY FACILITY CONTAINS THE COMBAT DEVELOPMENTS EVALUATION CENTER WHOSE PRIMARY FUNCTION IS TO DEVELOP AND CONDUCT WARGAME EXERCISES.

CAPABILITIES:

- o INSTRUMENTATED WARGAME PLAYERS
  - INDIVIDUAL FOOT SOLDIERS
  - VEHICLES
  - ROTORCRAFT
  - FIXED WING AIRCRAFT
- o RANGE PROVIDES
  - POSITION LOCATION FOR ALL PLAYERS (APPROX 75)
  - MESSAGE TRANSMISSION TO AND FROM ALL PLAYERS
  - REAL-TIME CASUALTY ASSESSMENTS
- o OPERATIONAL ROTORCRAFT EVALUATIONS INCLUDING
  - NIGHT COMBAT
  - SENSOR SYSTEMS
  - PILOT WORKLOAD
  - AIR-TO-AIR NOE COMBAT TACTICS
- o DIRECT FIRE WEAPONS SIMULATION
  - LASER UNITS SIMULATE TANKS, ROTORCRAFT, LARGE/SMALL GUNS
- o CENTER OF EXCELLENCE FOR AI
  - SYMBOLICS PROCESSOR

RANGE FEATURES:

- o ABSOLUTE POSITION FOR ROTORCRAFT ± 10 METERS, W, X, Y AND UP TO 5M IN Z OUT OF GROUND EFFECT

TABLE 15.

FLIGHT TEST RANGE AND FACILITIES REVIEW: NAVAL AIR TEST CENTER, PATUXENT RIVER, MD

THE MISSION OF THE NATC INTEGRATED RANGE IS TO EVALUATE TOTAL AIRCRAFT/WEAPONS SYSTEMS PERFORMANCE UNDER ACTUAL FLIGHT CONDITIONS FOR THE NAVY. IT ALSO SUPPORTS FLIGHT TESTING FOR OTHER AGENCIES AND DEFENSE CONTRACTORS.

TEST CAPABILITIES INCLUDE:

- O AIRSPEED AND ALTITUDE CALIBRATIONS
- O ANTENNA PATTERNS
- O HIGH ANGLE OF ATTACK EVALUATION
- O WEAPON DELIVERY ACCURACY
- O NAVIGATION SYSTEMS EVALUATION
- O ACOUSTIC SYSTEM TESTING
- O LANDING AND TAKEOFF PERFORMANCE
- O WEAPONS SEPARATION EVALUATION
- O EW SYSTEM EVALUATION AND COMMUNICATIONS JAMMING
- O SEA-SURFACE SENSOR ANALYSIS
- O FLYING QUALITIES
- O STRUCTURAL AND VIBRATION ANALYSIS
- O ENGINE PERFORMANCE

RANGE FEATURES:

- O CONTROLS OVER 500 SQUARE MILES OF AIRSPACE WITHIN CHESAPEAK BAY AND WITH NASA WALLOPS, CONTROLS AN EXTENDED RANGE 500 MILES INTO ATLANTIC
- O AIRBORNE INSTRUMENTATION: INVENTORY OF OVER 2000
- O TELEMETRY FOR UP TO 5 MISSIONS SIMULTANEOUSLY

TABLE 16.

COMPATIBILITY OF NRCFRF WITH EXISTING RANGES

NELLIS AFB

- o NRCFRF COULD POTENTIALLY OPERATE IN CONJUNCTION WITH NELLIS UNDER SPECIAL CIRCUMSTANCES SUCH AS:
  - EVALUATION OF A NRCFRF INNOVATION FOR POSSIBLE USE AT NELLIS
    - FLIGHT SAFETY HYPERSURFACE
  - SECURE MRGUS FOR EVALUATING CLASSIFIED AIRCRAFT IN AIR COMBAT
- o NRCFRF WOULD HAVE TO BE COMPATIBLE WITH NELLIS SYSTEM
  - SPACE POSITIONING SHOULD BE OK. NELLIS PLANS TO SWITCH TO GPS
  - USE ONE MRGU AT NELLIS TO INTERFACE WITH THEIR GROUND SYSTEM
  - OTHER MODS MAY BE NEEDED DEPENDING ON SPECIFIC TESTS
- o ASSESSMENT OF RELATIVE MERIT
  - ALTHOUGH TECHNICALLY FEASIBLE, IT IS UNLIKELY BECAUSE OF THEIR CHARTER AND HEAVY SCHEDULE
  - NELLIS AIRCRAFT HAVE SUPPORTED NASA TEST AS THREATS AND WOULD PROBABLY DO SO WITH NRCFRF

NAVAL AIR STATION, FALLON

- o VIRTUALLY SAME ANSWER AS FOR NELLIS

NAVAL WEAPONS CENTER (NWC)

- o NRCFRF COULD OPERATE IN CONJUNCTION WITH NWC TO SUPPORT NAVY TEST PROGRAMS
  - DRONE FLIGHT TESTS
  - WEAPONS AND DELIVERY PERFORMANCE EVALUATION
  - REAL-TIME FLIGHT EXPERIMENT SUPPORT
  - HIGHLY CLASSIFIED PROGRAM
  - OTHERS
- o NWC COULD PROBABLY USE NRCFRF DIRECTLY BECAUSE OF PROXIMITY RATHER THAN TRY TO MAKE NWC AND NRCFRF SYSTEMS COMPATIBLE
- o ASSESSMENT OF RELATIVE MERIT
  - DEFINITELY WORTH DISCUSSING AT PROPER TIME
  - NWC RANGE AND REAL-TIME SUPPORT CAPABILITY SIGNIFICANTLY BEHIND DFRF
  - NWC MIGHT ACTUALLY WANT TO PURCHASE MRGUS

FORT HUNTER-LEGGETT / FORT ORD

- o NRCFRF WOULD BE EXCELLENT FOR SUPPORTING ARMY FLIGHT TEST PROGRAMS AT FORT HUNTER-LEGGETT
  - PILOT-VEHICLE SYSTEMS INTERFACE ISSUES
  - AUTOMATED NOE
  - HELICOPTER AIR-TO-AIR COMBAT
  - LHX EVALUATIONS
  - OTHERS
- o WOULD USE MRGUs AND RAPs WITH SATELLITE LINKS TO DFRF
  - UNLIKELY THAT THEY WOULD DEVELOP OWN CAPABILITY
- o ASSESSMENT OF RELATIVE MERIT
  - DEFINITELY WORTH DISCUSSING AT PROPER TIME
  - MIGHT WANT TO PURCHASE MRGU

NAVAL AIR TEST CENTER (NATC)

- o NRCFRF COULD OPERATE IN CONJUNCTION WITH NATC ALTHOUGH THEY ARE FAIRLY WELL SELF SUFFICIENT. THE UP-LINK TIED TO EXTENSIVE COMPUTATION WOULD BE A NEW CAPABILITY FOR NATC. HAVING MRGU/RAP AT NATC COULD BE USEFUL TO:
  - ASSIST IN JOINT DFRF/NATC FLIGHT PROGRAMS
  - NATC COULD USE NRCFRF TEST SUPPORT CAPABILITIES
- o DIFFICULT TO MAKE SYSTEM TOTALLY COMPATIBLE. HOWEVER LOCATING A MRGU AT NATC AND USING STANDARD POD WOULD GIVE THEM ACCESS TO NRCFRF
  - WORTH DISCUSSING TO MAKE CERTAIN ELEMENTS COMPATIBLE
    - O GPS SPACE POSITIONING SYSTEM
    - O UP-LINK SYSTEM
    - O STANDARD POD AND MODULES
    - O SATELLITE RELAY
    - O INTERFACE BETWEEN MRGU/RAP AND NATC SYSTEM
- o ASSESSMENT OF RELATIVE MERIT
  - DEFINITELY WORTH DISCUSSING AT PROPER TIME
  - HAVING COMPABILITY IDENTIFIED ABOVE SHOULD BE ATTRACTIVE TO NATC
  - COULD BE HELPFUL TO HAVE MRGU AT NATC FOR NASP FLIGHT TEST SUPPORT

TABLE 17.

UNIQUE FEATURES OF NRCFRF: CHARTER

NRCFRF WOULD HAVE UNIQUE CHARTER

SUPPORT FLIGHT RESEARCH AND ADVANCED TECHNOLOGY DEVELOPMENT AS WELL AS TEST AND EVALUATION

REQUIRES

- EXTENSIVE REAL-TIME EXPERIMENT SUPPORT
- LARGE QUANTITIES OF HIGH QUALITY DATA
- KNOWLEDGEABLE FLIGHT RESEARCH AND SUPPORT ENGINEERS AND TECHNICIANS
- EXTENSIVE SUPPORT SIMULATION AND ANALYSIS CAPABILITY
- FLEXIBILITY AND ADAPTABILITY
- WIDE RANGE OF VERY DIVERSE VEHICLE AND SYSTEMS

DOD FLIGHT TEST CENTERS' CHARTERS

NELLIS AFB AND NAS FALLON

"STRICTLY AIR COMBAT TRAINING"

EXCELLENT FOR WHAT THEY DO BUT NO FLIGHT TEST

MEANS:

- SET ROUTINE AND HIGH UTILITY RATE REQUIRED
- HUNDREDS OF AIRCRAFT AT A TIME
- OPERATIONAL SYSTEMS ONLY (NO ADVANCED TECHNOLOGY OR FLEXIBILITY)

NAVAL WEAPONS CENTER

RDT&E FACILITY FOR NAVY AIR WARFARE SYSTEMS, PRIMARILY FOR AIR-TO-AIR AND AIR-TO-GROUND ORDNANCE

MEANS:

- OPERATE DRONES FOR TARGETS
- USE OPERATIONAL AIRCRAFT
- RANGE AND INSTRUMENTATION PRIMARILY FOR ORDNANCE DELIVERY

FORT HUNTER-LEGGETT/FORT ORD

ARMY COMBAT RDT&E CENTER INCLUDING AIRCRAFT AND GROUND FORCES. PRIMARILY CONDUCTS WARGAMES.

MEANS:

- NOT WELL SUITED FOR EXPERIMENTAL AIRCRAFT
- WILLING TO CONSIDER R&T PROGRAMS BUT FACILITIES LIMITED
- CAN PROVIDE REALISTIC ARMY COMBAT SITUATION

NATC

TOTAL AIRCRAFT/WEAPONS SYSTEMS TEST AND EVALUTION

ALSO SUPPORT FLIGHT TESTING OF ADVANCED AIRCRAFT/SYSTEMS

MEANS:

- CLOSEST CHARTER TO NRCFRF, HOWEVER, THE FACILITIES ARE DRIVEN BY T&E OF NEW NAVY AIRCRAFT/WEAPONS SYSTEMS
- MULTIPLE "HIGH PRODUCTION" TESTS SIMULTANEOUSLY
- GEARED TO HIGH UTILITY RATE
- LIMITED FLEXIBILITY

TABLE 18.

UNIQUE FEATURES OF NRCFRF: CAPABILITIES

NRCFRF WOULD HAVE UNIQUE CAPABILITIES

- EXTENSIVE COMPUTATION POWER LINKED WITH AIRCRAFT TO OPERATE IN EFFECT AS REAL-TIME EMBEDDED COMPUTERS
  - MULTIPLE MINICOMPUTERS
  - MULTIPLE LOGIC PROCESSORS
  - MULTIPLE IMAGE/GRAPHICS PROCESSORS
  - OTHER SPECIAL PURPOSE PROCESSORS IF NEEDED
- GRATER REAL-TIME COMPUTATIONAL SUPPORT FOR ANALYSIS OF FLIGHT TEST DATA DURING THE FLIGHT
- ENHANCED FLIGHT SAFETY FOR CRITICAL FLIGHT TESTS THROUGH REAL-TIME PREDICTIONS OF EXCEEDING SAFETY LIMITS
- INTEGRATION OF SIMULATION INTO FLIGHT TEST TO PROVIDE REALISTIC ENVIRONMENT AND PILOT WORKLOAD SITUATION FOR PILOT-VEHICLE/SYSTEM RESEARCH AND TECHNOLOGY EVALUATION
  - THREATS
  - OFFENSIVE AND DEFENSIVE WEAPONS
- MULTIPLE AIRCRAFT OPERATIONS (M ON N) FOR FLIGHT RESEARCH AND TECHNOLOGY PROGRAMS
- REDUNDANT REMOTE COMPUTATION AND DATA LINKS FOR CONDUCTING FLIGHT CRUCIAL FUNCTIONS SAFELY
- REMOTE AND MOBILE OPERATIONS WITH ALL THE ABOVE CAPABILITIES PLUS SECURE FACILITIES IF NEEDED FOR HIGHLY CLASSIFIED PROGRAMS

TABLE 19.

UNIQUE FEATURES OF NRCFRF: ABILITY TO SUPPORT DOD

NRCFRF COULD PROVIDE UNIQUE SUPPORT TO DOD

- FULL RANGE OF REMOTE COMPUTATIONAL SUPPORT, SPACE POSITIONING TEST MONITORING AND MISSION CONTROL, ETC., AT DOD FLIGHT TEST CENTERS VIA MRGUs, RAPs, AND RELAY DATA LINKS, E.G.,
  - HELICOPTER NOE AND AIR-TO-AIR COMBAT OPERATIONS AT FORT HUNTER-LEGGETT
  - JOINT NAVY/NASA FLIGHT TEST PROGRAMS AT NATC AND DFRF
- REALISTIC COMBAT ENVIRONMENT (M ON N, THREATS, WEAPONS SIMULATION) FOR FLIGHT EVALUATION OF DOD ADVANCED TECHNOLOGY PROGRAMS (DARPA, AF, NAVY, AND ARMY)
  - AUTOMATED WINGMAN
  - PILOTS ASSOCIATE PROGRAM
  - ATF AND LHX PROTOTYPE FLIGHT TESTS AND ADVANCED DEVELOPMENT

TABLE 20

UNIQUE FEATURES OF NRCFRF: ABILITY TO SUPPORT NASP

NRCFRF COULD PROVIDE UNIQUE SUPPORT TO NASP

- EXTENSIVE REAL-TIME EXPERIMENT SUPPORT TO ASSURE THE BEST RESULTS FROM FLIGHT TESTS, E.G.,
  - ESTIMATION OF NET THRUST
  - PREDICTION OF AEROTHERMODYNAMIC HEATING
  - PREDICTION OF VEHICLE STABILITY
- IMPROVED FLIGHT SAFETY THROUGH PREDICTIONS OF EXCEEDING SAFETY LIMITS
  - STABILITY
  - AEROTHERMODYNAMIC HEATING ("HOT SPOTS")
- PRECISE TRAJECTORY CONTROL AND ENERGY MANAGEMENT
- MORE FLEXIBILITY IN EVALUATING MISSION AVIONICS FUNCTIONS THROUGH REMOTE COMPUTATIONS

5.0 ROBOTIC WINGMAN SCENARIO DEFINITION

5.1 The Robotic Wingman Concept

The end goal for the Robotic Wingman (RW) concept is the exploitation of a separate fighter entity to augment manned fighter aircraft in the same tactical formation. This exploitation focuses on the "perfect" coordination of a pair of fighters in air combat. This coordination of efforts is derived through the technical emphasis of the respective strengths of man and machine. The concept requires real time artificial intelligence (AI) technology applied to functional task execution in the combat environment.

The artificial intelligence architecture parallels the distinct division of roles between the manned flight lead and the automated, robotic wingman. The flight lead addresses tactics, planning, and mission requirements. The RW addresses implementation of basic wingman responsibilities, flight lead directions, and coordinated information control. Task implementation is based on pre-defined contractual agreements using acquired information developed internally through expert systems.

The distinction between the Robotic Wingman concept and intelligent remotely piloted vehicles (RPV) is in tactical employment. RPVs operate independent from manned aircraft and perform preplanned or remotely directed missions which do not require close coordination or close proximity flying to manned aircraft. RWs fly as wingmen to manned aircraft performing all of the functions of a wingman in a small robotic highly maneuverable fighter aircraft.

5.2 Automation in Air Combat

In air combat, the pilot is limited in his ability to assimilate and perform multiple tasks simultaneously. He increases his multiple task performance to a limited degree through extensive training. A large amount of this training is directed at rudimentary tasks which could easily be automated. Only a small share of the training is oriented at developing the higher level situational skills mandatory for longevity in the air combat arena. In fact, the qualitative success in combat varies directly with the effectiveness of pilot coordination of efforts (read possible automation). The environment requires man to process and perform multiple tasks simultaneously in order to succeed. Unfortunately, man tends to process as a serial processor of information. The better pilots learn to consistently prioritize so that they can concentrate on smaller tasks groupings. Machines can release humans from low priority tasks and present information in a serial format.

There are positive and negative aspects of automation in combat. Technology is working very hard at reducing the pilot's workload. The pilot community eagerly awaits sensor integration. They see the sorting, integration, and prioritization of information as important in keeping the pilot below his task saturation threshold. The increasing availability of data to the pilot multiplies the complexity of tactical air warfare operations. The capability to analyze an intricate dynamic environment, determine an optimum course of action and then execute an appropriately timed maneuver, a problem of data reduction and information sorting, remains the pilot's ultimate concern.

Yet, no pilots will desire to fly in any totally automated aircraft (as a wingman or a flight lead). The operational community must be satisfied that the human will be in the loop, increased survivability and lethality will be truly achieved, and the system is usable. The primary method for the RW program to satisfy this concern is through tactical flight demonstrations proving the operational utility of the weapons platform. However, the initial stages of the program may show little operational utility in terms of mission effectiveness measures for the MvN environment. The RW should fit within present day definition of wingman functionality. Those functions are well defined and already accepted by the operational community.

The most important point is that wingman performs specific functions or tasks for his flight lead and has a major effect on force survivability and effectiveness. The wingman, human or not, does not advise the flight lead to perform a tactic. The wingman, manned or robotic, functions only as an extension of the flight lead's will. He exists to provide mutual support to increase force survivability and effectiveness.

Man performs well as an independent thinker, but does not always operate well in concert with another man. Since man is not always a perfect wingman, technological development should specifically address that problem.

The purely RW has positive features such as transference of information, reliability of automated performance for repetitive functions, and increasing multi-directional awareness on a constant, non-training sensitive basis. Conversely, any artificial intelligence program must not be conceptually focused on the tactical decision arena in which humans are most well suited. The thrust of the program should be to design a brilliant unmanned fighter aircraft designed for one position, as the wingman of a manned fighter.

5.3 Flight Demonstration Concept

This concept involves the use of remote ground computers to host all the required expert systems, trajectory generation and control algorithms, and automated communication systems which would have to be onboard an operational RW. A remotely augmented vehicle type facility as depicted in Figure 27, is used to fly the RW closed loop in a series of flight demonstrations of increasing complexity. In this fashion, concepts are flight demonstrated which require computation loads which cannot be executed on airborne computers for some time to come. The RW demonstration aircraft is manned by a pilot who performs all takeoffs, landings, climbs and descends to the test range and acts as safety pilot while the RW is being flown closed loop through the facility. In addition, all the sensor technology required to design an operational RW is bypassed in this program. The required sensor information is simulated through the use of ground radar based real-time space positioning. Thus, the program is free to concentrate on the development of AI technology as applied to the RW concept while the necessary sensor and computer technologies required to support an operational system are being pursued by other programs.

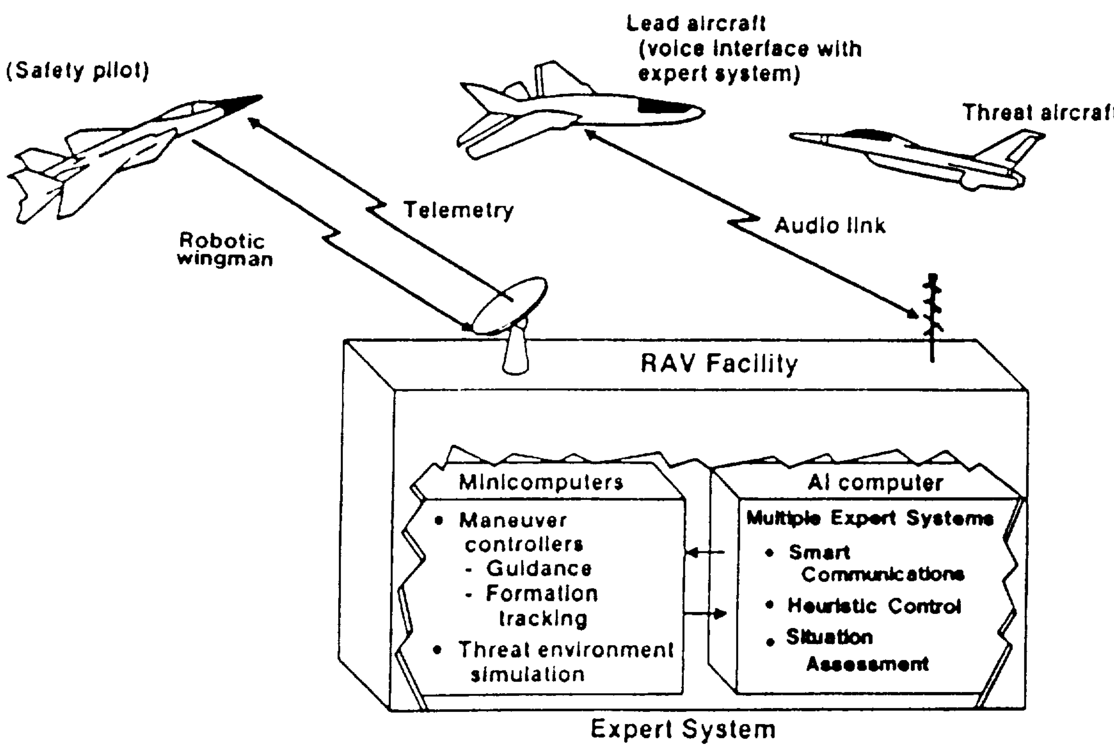

FIGURE 27. FLIGHT DEMONSTRATION CONCEPT FOR ROBOTIC WINGMAN

5.3.1 Flight Demonstration Scenario

The fighter sweep mission, without an integrated air defense system (IADS), was selected for the demonstration scenario for the robotic wingman program because:

1. Sweep is one of the simplest missions for employment since it has the least number of mission related restrictions.

2. Without the addition of IADS, existing equipment can provide the needed target sensing and acquisition. Sweep provides a clear medium for the integration of fire control, flight path control, and target sensing and acquisition interpretation.

3. All other air-to-air missions needed some system for positive target identification. Military technology has yet to solve that particular problem outside of the human eyeball. Unfortunately, even if this program used vision systems for identification, the RW would be well inside the threat's electronic detection capability and missile envelopes. Any air-to-ground mission would have required an expert system for vision interpretation. Present AI programs are having a difficult time with vision operations.

4. A finite navigational data base and minimal coordination with outside agencies are two advantages of a sweep scenario. Low altitude air-to-ground operations need an extremely large terrain data bank plus the precise mapping of local terrain.

5. All air-to-ground missions would have required the use of highly sophisticated target sensing and acquisition equipment, most of which has yet to be developed. A system capable of clear separation between friendly and enemy ground forces would be a major task not appropriate for this program's objective.

5.3.2 Scenario Definition

The RW program focuses on incremental flight demonstrations of increasingly integrated tasks. The scenario is built up incrementally so RW capabilities are developed separately and then carefully meshed to demonstrate synergism. This approach allows discrete development of subsystems. Logical partitioning and standard interfaces are necessary to permit later addition of sensors and weapons for more highly developed systems. The scenarios are easily expandable into more complex operations.

The development program is based on the USN/USAF fighter training unit approach. Initially, individual tasks are learned separately. Those tasks are slowly integrated as capability is proven in limited scenarios. Eventually, multiple tasks are performed simultaneously in increasingly complex scenarios. The RW scenario definition and program reflects this philosophy.

The scenarios are stepped for proof of concept, demonstration feedback, learning curve, and safety considerations. Real world considerations can now be entered into the growth-oriented development of the artificially intelligent RW. The individual levels of one type of demonstration do not correspond chronologically with other functional demonstration levels.

For this project's demonstration to be accepted by the tactical community, the system is directed towards the multi-aircraft versus multi-aircraft (M versus N) air combat scenario. Even though many portions of the demonstration will initially be 1 versus 1, or 2 versus 1, the evaluation is oriented for high task load engagements. Yet this limited scenario should not engage the project in multiple concept integration problems. Therefore, the entire scenario does not include SAM system, AAA, a FEBA, political borders, etc.

The RW must operate under present day rules of combat, not some "projected" set of ideas on future combat. Multiple combat roles can eventually be incorporated into the system after core validation. RW operations must reflect the real world task division and thought process. The conceptual approach should map current and historical fighter employment concepts.

The RW will demonstrate the capability to perform basic tactical fighter wingman responsibilities as part of the flight demonstration. A wingman must be able to fly formation, detect threats, execute specific maneuvers, sort enemy formations and tactics, target the correct bandit, and select the appropriate weapons.

The recommended mission scenario is partitioned into near-term, mid-term, and far-term projections. The division relates to the respective time frames for the projected program effort. The separate demonstrations reflect the functional tasks presently performed by a human wingman.

With these considerations in mind, the scenarios developed are briefly described below for the near-term (3 years), mid-term, and far-term demonstrations. The demonstrations are initially divided into four categories: Formation Flying (Form), Sensor Detection (SD), Tactical Intercept (TI), and Threat Reaction (TR). As the scenarios become more complex, various elements of the original four categories are integrated.

Formation Flying

Five scenarios of formation flying demonstrations are defined from flying simple tactical formation through various types of tactical turns to the execution of correct tactics with respect to position during intercepts, search, and threat reaction.

Tactical Intercept

Five scenarios of tactical intercept demonstrations are defined from flying specific radar intercept and conversion profiles to coordinated intercepts against multiple targets.

Sensor Detection

Five scenarios of sensor detection, targeting, sorting, electronic countermeasures (ECM) and radar homing and warning (RHAW) recognition are defined from simple radar manipulations according to pre-stated instructions to multiple target sorting and detection.

Threat Reaction

Five scenarios of threat reaction demonstrations are defined from flying specified maneuvers to negate or threaten a bandit to expert system selected maneuvers.

Integrated System

A final demonstration is defined which combines all of the tasks described in previous demonstrations.

5.3.3 Requirements

Description of Sensor Requirements

The sensor suite required in the RW airplane to perform the near-term demonstrations includes the standard F-18 flight control sensors (rate gyros, accelerometers, pitot and static pressure, angle-of-attack) and inertial navigation system (INS) sensors (accelerometers). These are required to service the standard F-18 digital control laws and the aircraft's onboard INS. No other actual sensors are required on the RW other than standard radios and navigational equipment.

Simulation sensor information must be generated in the NRCFRF from radar information and RHAW information. This information will simulate the RW radar set and RHAW receiver. In addition, a tracking system based on some advanced sensor and/or data link which allows the RW to track the lead aircraft, must be simulated.

NRCFRF Processing Requirements

The NRCFRF processing requirements will be extensive. Several skeletal expert systems will be running concurrently in addition to a trajectory generation and control algorithm, radar and RHAW simulations, a scenario geometry algorithm, a lead aircraft tracker algorithm, real time data analysis and display generation algorithms, and input/output support software.

In addition, a voice recognition and voice synthesis system must be able to recognize a small set of commands from the lead aircraft pilot and synthesize voice responses back to the lead aircraft as if they were coming from the RW.

We envision a requirement for either a parallel processor to execute the multiple expert systems or several symbolics processors networked to the existing computer facility. It may be necessary to enhance the existing computer facility with additional computers.

Observer Station Requirements

A ground observation station is required to allow observers to monitor the experiment. The station should include displays of the scenario and cockpit views from all aircraft similar to Air Combat Maneuvering Range (ACMR) type displays. To generate this information, display generation algorithms and appropriate device drivers must be resident in the NRCFRF.

5.4 Summary

This RW project can form the basis for an integrated fighter development road map for sensors, aircrew displays, expert flight lead systems, aircraft self-protection systems, and aircraft internetting. Also, new RW aircraft designs can be produced to fully implement the inherent strengths found in a "manned" wingman without a human body residing therein. The RW could be integrated with the Enhanced Fighter Maneuverability program to prove the usefulness of the application.

The ability to employ effective non-man rated combat systems under close control of man and in concert with his own activities can completely redefine our current concept of mutual support. The development of an extremely small, powerful, cost effective engine, miniaturized avionics, and lethal weapons could make this system the true "stinger" in any fighter operation.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the limited feasibility study of the National Remote Computational Flight Research Facility (NRCFRF) the following major conclusions were reached:

1. There exists a strong research and technology justification for NRCFRF in providing early flight evaluation of computationally intensive flight system

concepts and in providing a more complete flight testing environment and support capability.

2. NRCFRF would be unique in charter and capabilities. In addition to NASA programs, it appears that it could provide unique and beneficial support to DOD advanced aircraft and technology programs and to the joint DOD/NASA National Aerospace Plane (NASP) Experimental Vehicle flight test program.

3. Providing the test range and facilities to establish NRCFRF appear feasible and within current state-of-the-art. The current Western Aeronautical Test Range including the Remotely Augmented Vehicle Facility, provides a nucleus for an evolutionary expansion to the full NRCFRF capabilities.

4. With regard to the Robotic Wingman Scenario Definition task, a feasible and technically significant set of flight demonstration scenarios has been defined that can be accomplished in the near-term and far-term program.

The following recommendations are made with respect to NRCFRF:

1. NASA should consider developing a National Remote Computational Flight Research Facility to support NASA and DOD programs.

2. Focus on the requirements to support NASP but make provisions for expanding capabilities to meet the other R&T requirements defined in this report.

3. A Master Plan should be prepared for an evolutionary development and growth of NRCFRF, including:

   - Capabilities Requirements and Schedule
   - Overall Systems Architecture
   - Near-term Development Plan
   - Long-term Expansion Capabilities
   - Construction of Facilities Plan
   - Tracking and Data Systems Plan
   - Test Methods and Applications Hardware/Software Plan

4. The Master Plan should consider:

   - Evolutionary computational network with multiple general purpose and special purpose computers for real-time processing that are continually upgraded to provide state-of-the-art capability;

   - GPS based space positioning system with provisions for augmentation with other space positioning information, e.g., inertial navigation systems, radar altimeters, and tracking radars;

- o Data/communications link system for multiple simultaneous aircraft operations;
- o Mobile Remote Ground Units (MRGU) and Remote Airborne Platforms (RAP) with remote computational as well as data relay capabilities;
- o Standard Vehicle Interface Units with selectable modules packaged in pods that fit standard missile launchers or for internal aircraft installations;
- o Flexible pilot-vehicle interface system capability using a combination of onboard and remote computation;
- o Secure operations using MRGUs and/or RAPs;
- o Redundancy requirements and concepts for using remote computation in flight crucial functions; and,
- o Extended range coverage using MRGUs and/or RAPS and/or TDRSS.

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16. Abstract

This study investigates the extension of the NASA Ames-Dryden remotely augmented vehicle (RAV) facility to accommodate flight testing of a hypersonic aircraft utilizing the continental United States as a test range. The study also documents the development and demonstration of an automated flight test management system (ATMS) that uses expert system technology for flight test planning, scheduling, and execution.

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