RTI/4028/01-03F

FINAL

BASELINE ASSESSMENT

NASA GODDARD SPACE FLIGHT CENTER WALLOPS FLIGHT FACILITY

September 1989

Prepared Under Contract No. DTR-57-87-C-00116

By

RESEARCH TRIANGLE INSTITUTE
CENTER FOR SYSTEMS ENGINEERING
FLORIDA OFFICE

Mr. Loyd C. Parker
Mr. Jerry D. Watson
Mr. James F. Stephenson

For

U.S. DEPARTMENT OF TRANSPORTATION
OFFICE OF COMMERCIAL SPACE TRANSPORTATION
WASHINGTON, D.C. 20590

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

BASELINE ASSESSMENT

WALLOPS FLIGHT FACILITY

INTRODUCTION

At the direction of the Office of Commercial Space Transportation (OCST), Research Triangle Institute (RTI) conducted a study of the Goddard Space Flight Center/Wallops Flight Facility (GSFC/WFF) at Wallops Island, Virginia. The purpose of the study was to establish a baseline upon which OCST could assess whether or not a commercial launch proposal is safe. Since the emphasis of the study is upon launch vehicles, particularly orbital launch vehicles, many activities at the WFF have not been treated with the same degree of attention. These range from a research airport with aeronautical research and airborne geoscience/applications programs to extensive activities associated with targets, drones and balloons, many of which are performed off range.

The following information is presented as a result of this effort:

A. GENERAL INFORMATION

1. Range History and Experience - In 1945, NASA's predecessor agency, the National Advisory Committee for Aeronautics (NACA), established a launch site on Wallops Island, Virginia, under the direction of the Langley Research Center, then a field laboratory station of NACA. This site was designated the Pilotless Aircraft Research Station and assigned the mission of conducting research to supplement wind tunnel and laboratory investigations into the problems of flight. When Congress established the National Aeronautics and Space Administration (NASA) in 1958 and absorbed Langley Research Center and other NACA field centers and research facilities, the Pilotless Aircraft Research Station became a separate facility - Wallops Station -operating directly under NASA Headquarters in Washington, D.C. It became Wallops Flight Center in 1974, and the name was changed to Wallops Flight Facility (WFF) in 1981 when it became part of Goddard Space Flight Center (GSFC), Greenbelt, Maryland.

Since 1945, Wallops has launched approximately twelve thousand suborbital research vehicles (sounding rockets and research balloons) in the quest for information on the flight characteristics of airplanes, launch vehicles and spacecraft, and to increase the knowledge of the Earth's upper atmosphere and the near space environment. Several hundred experiments are sent aloft each year. The launch vehicles, consisting of from one to four rocket stages, vary in size and power from the small Super Loki meteorological rockets to the four-stage Scout vehicle with orbital capability. To date, 21 orbital satellites have been launched on the Scout vehicle from Wallops as indicated in **Table 1**[1]. An additional 19 suborbital Scouts have been launched carrying probes and reentry experiments.

TABLE 1. WFF SCOUT ORBITAL LAUNCH RECAP		
NAME	**DESCRIPTION**	**LAUNCH DATE**
S-56	Failed to orbit; second stage ignition malfunction	12/04/60
Explorer IX	For measuring atmospheric density and drag	02/16/61
S-55	Failed to orbit; third stage ignition malfunction	06/30/61
Explorer XIII	To determine the puncture hazard of micrometeorites which may be encountered by spacecraft	08/25/61
Explorer XVI	A second micrometeoroid satellite	12/16/62
Air Force Satellite	Geophysical Research satellite	06/28/63
Ariel II	United Kingdom satellite	03/27/64
Explorer XXIII	Another micrometeoroid satellite	11/06/64
San Marco I	First Italian satellite	12/15/64
Secor	U.S. Army geodetic satellite	08/10/65
Explorer XXVII	Beacon Explorer and geodetic satellite	08/29/65
Explorer XXX	Naval Research Laboratory IQSY Solar Explorer satellite	11/18/65
OV3-4	Air Force radiation detection satellite	06/10/66
Explorer XXXVII	Naval Research Laboratory solar radiation satellite (SOLRAD)	03/05/68
Orbiting Frog Otolith (OFO)	To study effects of weightlessness on inner ear along with "piggyback" Radiation Meteoroid satellite	11/09/70
Explorer 44	NRL SOLRAD-10C satellite	07/08/71
Eole	French weather satellite	08/16/71
Explorer 46	Meteoroid Technology Satellite (MTS)	08/13/72
Sage	The effects of aerosols and ozone on climate and environment quality	02/18/79
Ariel 6	British satellite - studies in the field of high-energy astrophysics	06/02/79
AF-16	Instrumented Test Vehicle for testing anti-satellite system	12/12/85

Also, approximately 142 sounding rockets have been launched over the past five years. They are listed in **Table 2**[2]. This is only a reflection of the NASA Sounding Rocket Program, not a comprehensive list of all sounding rocket launches.
Wallops is located on Virginia's eastern shore approximately 40 miles southeast of Salisbury, Maryland. The location of WFF in relation to nearby major population centers is shown in **Figure 1**[1]. It consists of three separate sections of real property:

(a) Main Base - Administrative offices, technical service support shops, a rocket inspection and storage area and an experimental research airport are located at the Main Base. In addition, there are such operational facilities as the Range Control Center, the main telemetry building, a large computer complex and the Management Education Conference Center.

(b) Wallops Island Launching Site - Wallops Island, a barrier island named after John Wallop, a 17th century surveyor, is located on the coast of Virginia approximately seven miles southeast of the Main Base. Separated from the mainland by two miles of marsh and inland waterway, the Island (approximately six miles long and about one-half mile at its widest point) is connected with the Mainland by a causeway and bridge. Located on the Island are launch sites, assembly shops, blockhouses, dynamic balancing facilities, some rocket storage buildings and related facilities.

(c) Wallops Mainland Site - Wallops Mainland, a half-mile strip at the opposite end of the causeway behind the Island, is the location for the long-range radars, communications transmitter facilities and command transmitters.[1]

2. WFF Organization - The Goddard Space Flight Center/Wallops Flight Facility is maintained and operated as a NASA research/test launch range. The Director of Suborbital Projects and Operations exercises overall jurisdiction and responsibility for all GSFC/WFF operations. The WFF organization is shown in **Figure 2**[3].

3. Wallops Launch Range - The Wallops Launch Range originates on Wallops Island, Virginia, and extends out into the Atlantic Ocean, utilizing the surface area and airspace above to conduct various flight operations. The principal Island facilities are those required to process, check-out and launch solid rocket boosters carrying scientific payloads on sub-orbital or low earth-orbit trajectories. Included are launch pads, launchers, blockhouses, booster preparation and payload check-out buildings, dynamic balance equipment, a timing facility, wind measuring devices, communications and control instrumentation, TV and optical tracking stations, surveillance and tracking radar units and other supporting facilities. Since the launch areas are located on the southern half of Wallops Island, most of the facilities mentioned here are in that area also, with special use facilities, such as balancing equipment, being located on the northern portion of the Island.

TABLE 2. NASA SOUNDING ROCKET LAUNCH RECAP			
FY Date	**Rocket Type**	**Range**	**Vehicle Success or Failure**
10-06-84	Nike Black Brant V	WSMR, New Mexico	S
10-22-84	Taurus Orion	WSMR, New Mexico	S
10-23-84	Taurus Orion	WSMR, New Mexico	S
12-10-84	Nike Black Brant V	WSMR, New Mexico	S
1-17-85	Aerobee 150	WSMR, New Mexico	S
1-23-85	Terrier Malemute	Sondre Stromfjord, Greenland	S
1-23-85	Black Brant X	Sondre Stromfjord, Greenland	S
1-28-85	Orion	Poker Flat, Alaska	S
2-7-85	Orion	Poker Flat, Alaska	S
2-8-85	Taurus Orion	WSMR, New Mexico	S
2-10-85	Terrier Malemute	Sondre Stromfjord, Greenland	S
2-10-85	Black Brant X	Sondre Stromfjord, Greenland	S
3-5-85	Taurus Orion	Sondre Stromfjord, Greenland	S
3-14-85	Taurus Tomahawk	Poker Flat, Alaska	S
3-15-85	Nike Orion	Fort Churchill, Canada	S
3-18-85	Black Brant V	WSMR, New Mexico	S
3-20-85	Taurus Tomahawk	Sondre Stromfjord, Greenland	S
3-20-85	Nike Tomahawk	Sondre Stromfjord, Greenland	S
3-22-85	Nike Orion	Fort Churchill, Canada	S
3-27-85	Nike Black Brant V	Fort Churchill, Canada	S
3-29-85	Nike Orion	Poker Flat, Alaska	S
3-29-85	Super Arcas	Poker Flat, Alaska	S

4-1-85	Nike Orion	Poker Flat, Alaska	S
4-1-85	Super Arcas	Poker Flat, Alaska	S
4-2-85	Orion	Poker Flat, Alaska	S
4-20-85	Nike Black Brant V	WSMR, New Mexico	S
6-14-85	Black Brant V	WSMR, New Mexico	S
6-24-85	Nike Orion	WFF, Virginia	S
6-26-85	Nike Orion	WFF, Virginia	S
8-3-85	Black Brant V	WSMR, New Mexico	F
9-6-85	Nike Orion	WSMR, New Mexico	S
9-7-85	Orion	WFF, Virginia	S
9-10-85	Orion	WFF, Virginia	S
9-10-85	Taurus Orion	WFF, Virginia	S
9-10-85	Nike Orion	WFF, Virginia	S
9-12-85	Nike Orion	WSMR, New Mexico	S
9-17-85	Orion	WSMR, New Mexico	S
10-16-85	Orion	WFF, Virginia	S
10-25-85	Nike Black Brant V	WSMR, New Mexico	S
11-10-85	Black Brant IX	Andoya, Norway	S
11-20-85	Taurus Nike Tomahawk	WFF, Virginia	S
12-14-85	Black Brant IX	WSMR, New Mexico	S
12-16-85	Black Brant IX	WSMR, New Mexico	S
1-18-86	Black Brant X	Andoya, Norway	S
2-1-86	Nike Black Brant V	WSMR, New Mexico	S
2-24-86	Black Brant IX	WSMR, New Mexico	S
2-26-86	Black Brant V	WSMR, New Mexico	S
3-7-86	Nike Black Brant V	WSMR, New Mexico	S
3-7-86	Taurus Orion	WSMR, New Mexico	S
3-13-86	Black Brant IX	WSMR, New Mexico	S
3-13-86	Black Brant V	WSMR, New Mexico	S
4-1-86	Black Brant X	Poker Flat, Alaska	S
4-3-86	Terrier Malemute	Poker Flat, Alaska	S
4-13-86	Black Brant X	Poker Flat, Alaska	S

4-18-86	Nike Orion	WSMR, New Mexico	S
4-22-86	Nike Black Brant V	WSMR, New Mexico	S
4-22-86	Black Brant X	WFF, Virginia	S
4-25-86	Nike Orion	WSMR, New Mexico	F
4-28-86	Taurus Nike Tomahawk	WFF, Virginia	S
5-13-86	Black Brant X	WFF, Virginia	S
5-13-86	Taurus Nike Tomahawk	WFF, Virginia	S
7-26-86	Nike Orion	Kiruna, Sweden	S
7-26-86	Nike Orion	Kiruna, Sweden	S
7-26-86	Nike Orion	Kiruna, Sweden	S
7-27-86	Super Arcas	Poker Flat, Alaska	S
7-29-86	Super Arcas	Poker Flat, Alaska	S
7-29-86	Super Arcas	Poker Flat, Alaska	S
8-2-86	Super Arcas	Poker Flat, Alaska	S
8-2-86	Super Arcas	Poker Flat, Alaska	S
8-24-86	Aries	WSMR, New Mexico	F
10-15-86	Nike Black Brant V	WSMR, New Mexico	S
10-22-86	Nike Black Brant V	WSMR, New Mexico	S
11-20-86	Orion	WFF, Virginia	S
12-15-86	Black Brant IX	WSMR, New Mexico	S
1-28-87	Black Brant IX	WSMR, New Mexico	S
1-31-87	Black Brant IX	Poker Flat, Alaska	S
2-17-87	Taurus Orion	WSMR, New Mexico	S
2-26-87	Terrier Malemute	Sondre Stromfjord, Greenland	S
3-5-87	Terrier Malemute	Sondre Stromfjord, Greenland	S
3-5-87	Taurus Nike Tomahawk	Sondre Stromfjord, Greenland	S
3-7-87	Black Brant X	Poker Flat, Alaska	F
3-21-87	Taurus Tomahawk	Sondre Stromfjord, Greenland	S
3-21-87	Nike Tomahawk	Sondre Stromfjord, Greenland	S

3-24-87	Nike Orion	WFF, Virginia	S
3-31-87	Black Brant IX	Sondre Stromfjord, Greenland	S
3-31-87	Taurus Nike Tomahawk	Sondre Stromfjord, Greenland	S
3-31-87	Taurus Nike Tomahawk	Sondre Stromfjord, Greenland	S
7-14-87	Super Arcas	Andoya, Norway	S
7-14-87	Super Arcas	Andoya, Norway	S
7-14-87	Super Arcas	Andoya, Norway	S
7-15-87	Taurus Orion	WFF, Virginia	S
7-15-87	Super Arcas	Andoya, Norway	S
7-26-87	Orion	WFF, Virginia	S
7-27-87	Taurus Orion	WFF, Virginia	S
7-27-87	Nike Black Brant V	WSMR, New Mexico	S
7-31-87	Black Brant IX	WFF, Virginia	S
8-7-87	Nike Black Brant V	WFF, Virginia	S
8-15-87	Black Brant IX	WSMR, New Mexico	S
9-27-87	Nike Black Brant V	WSMR, New Mexico	S
10-15-87	Orion	Andoya, Norway	S
10-15-87	Nike Orion	Andoya, Norway	S
10-21-87	Nike Orion	Andoya, Norway	S
10-21-87	Orion	Andoya, Norway	S
10-21-87	Nike Orion	Andoya, Norway	S
10-23-87	Nike Black Brant V	WSMR, New Mexico	S
10-28-87	Nike Orion	Andoya, Norway	S
11-12-87	Orion	Andoya, Norway	S
11-12-87	Nike Orion	Andoya, Norway	S
11-14-87	Black Brant IX	Woomera, Australia	S
11-18-87	Black Brant IX	Woomera, Australia	S
12-4-87	Black Brant IX	Woomera, Australia	S
12-11-87	Black Brant IX	WSMR, New Mexico	S
12-11-87	Black Brant IX	WSMR, New Mexico	S
1-19-88	Black Brant X	Poker Flat, Alaska	S

1-23-88	Black Brant IX	WSMR, New Mexico	S
1-29-88	Black Brant IX	WFF, Virginia	S
2-9-88	Black Brant IX	Poker Flat, Alaska	S
2-16-88	Black Brant IX	Woomera, Australia	S
2-28-88	Black Brant IX	Woomera, Australia	S
3-4-88	Black Brant IX	Poker Flat, Alaska	S
3-13-88	Black Brant IX	Woomera, Australia	S
3-17-88	Black Brant IX	WSMR, New Mexico	S
4-9-88	Black Brant V	Kiruna, Sweden	S
5-3-88	Nike Orion	WSMR, New Mexico	S
5-10-88	Nike Orion	WSMR, New Mexico	S
6-23-88	Black Brant IX	WSMR, New Mexico	S
7-27-88	Nike Black Brant V	WFF, Virginia	S
7-27-88	Taurus Nike Tomahawk	WFF, Virginia	S
9-10-88	Black Brant IX	WFF, Virginia	S
9-11-88	Black Brant IX	WSMR, New Mexico	S
9-15-88	Nike Black Brant V	WSMR, New Mexico	S
9-30-88	Special Projects	WFF, Virginia	S
10-20-88	Taurus Orion	Poker Flat, Alaska	F
10-24-88	Black Brant IX	WSMR, New Mexico	S
11-7-88	Black Brant V	Andoya, Norway	S
11-10-88	Black Brant V	WSMR, New Mexico	S
11-20-88	Black Brant V	WSMR, New Mexico	S
12-7-88	Nike Black Brant V	WSMR, New Mexico	S
12-17-88	Black Brant X	Andoya, Norway	S
1-9-89	Black Brant IX	WSMR, New Mexico	F
1-17-89	Black Brant IX	WSMR, New Mexico	S
1-30-89	Special Projects	Andoya, Norway	S

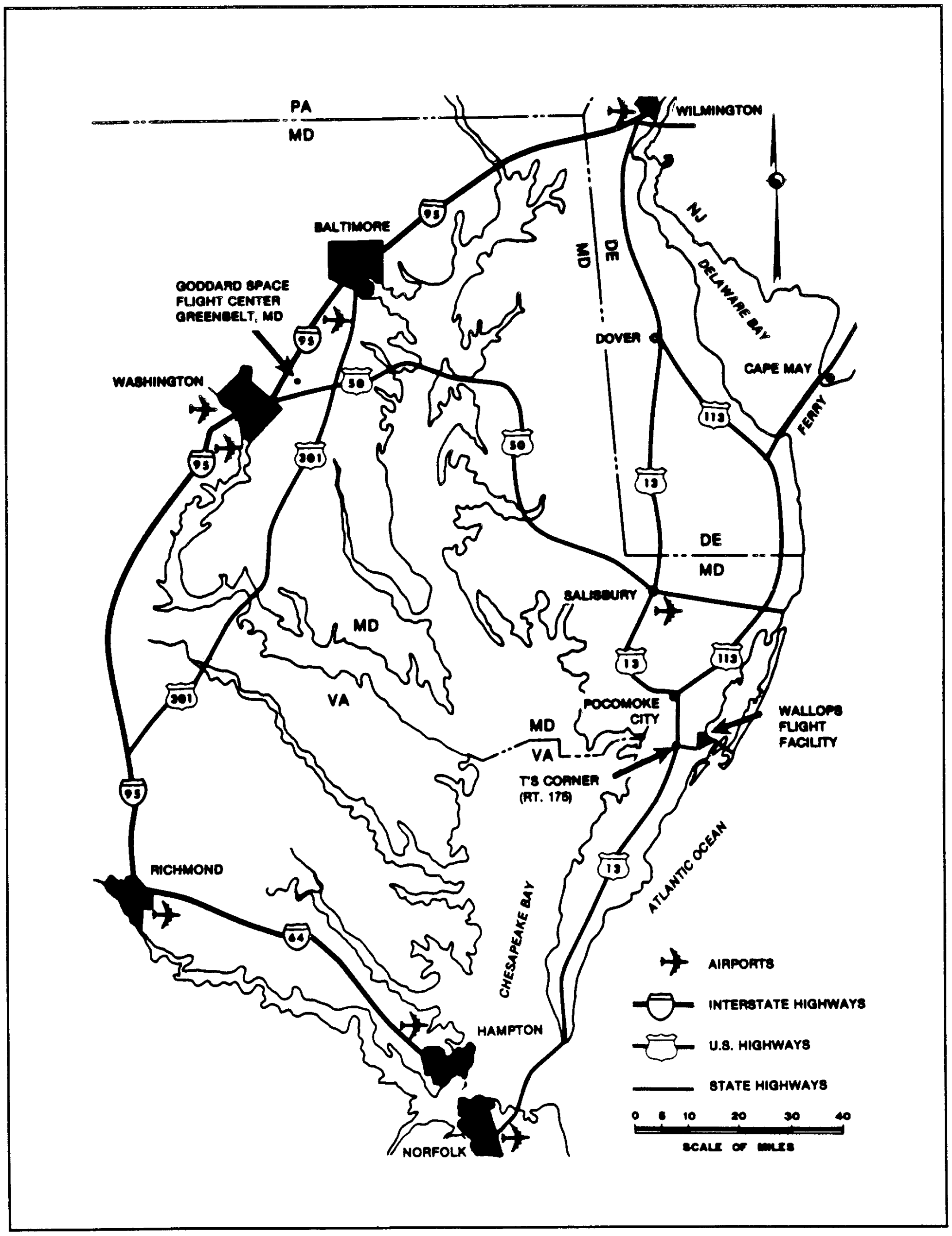


FIGURE 1. LOCATION OF WALLOPS FLIGHT FACILITY

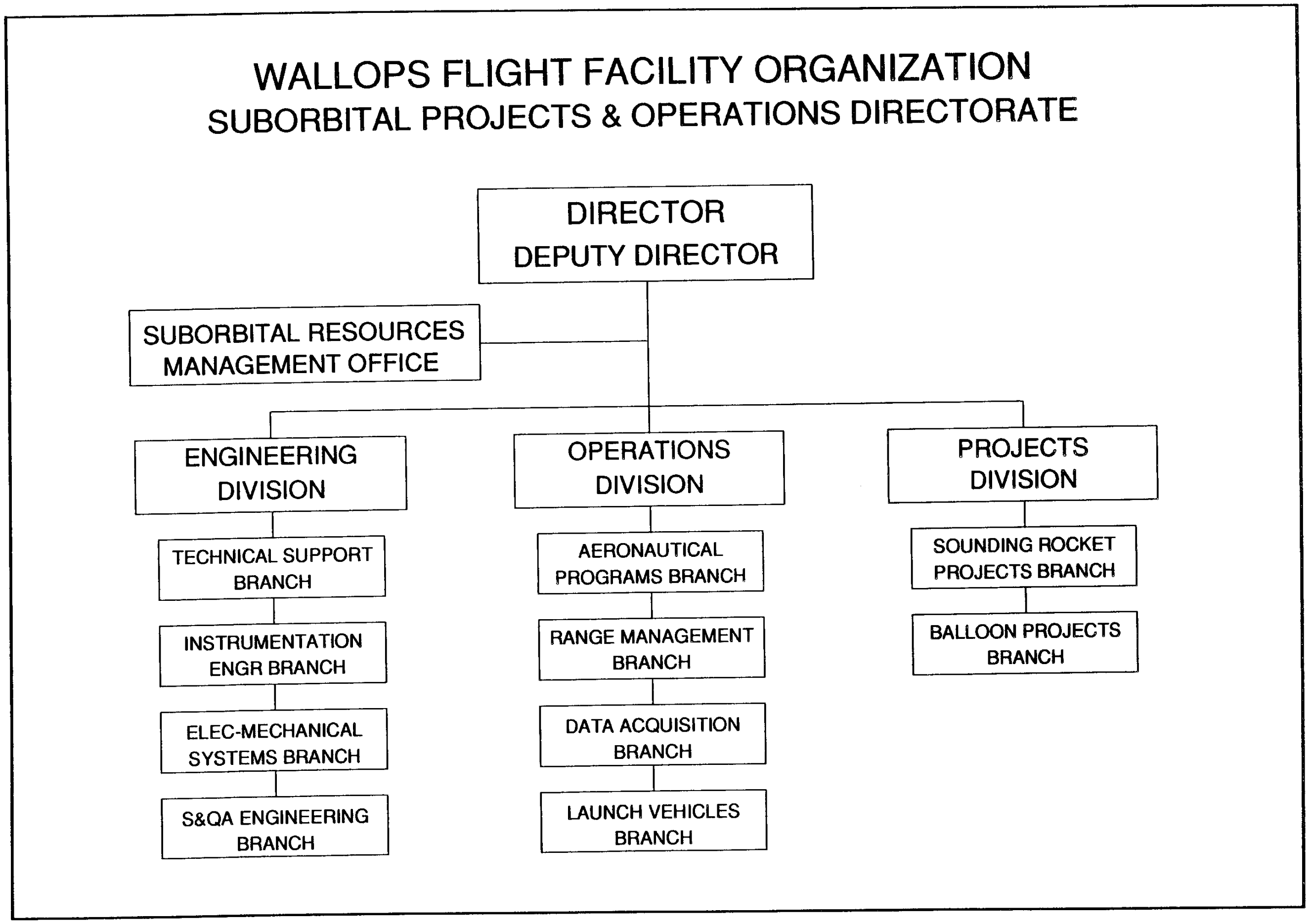


FIGURE 2. WALLOPS FLIGHT FACILITY ORGANIZATION

From time-to-time, ground-based scientific equipment requiring isolation from other activities may be located temporarily on the north half of the island.[1] **Figure 3**[1] shows the Wallops Flight Facility, Wallops Mainland and Wallops Island.

a. Complexes and Facilities - The WFF launch complexes are located on Wallops Island adjacent to the beach, see **Figure 4**[1] for WFF complex and facility locations, and consist of the following:

(1) Launch Area Number 0 - This area included one launcher (which has been removed), an assembly shop and a blockhouse. Large sounding rockets, such as Strypi, Super Chief and Black Brant were launched from a tubular launcher enclosed in a shelter. This site is currently inactive.

(2) Launch Area Number 1 - The launch tower at this site was 160 feet tall and could be adjusted in azimuth and elevation to the proper launch position (it has been removed). It was used primarily for launching the liquid-propellant Aerobee 150A vehicle, the Aerobee 350 (a larger version of the 150A), as well as the solid propellant Astrobee F and Black Brant V vehicles. The Aerobee sounding rockets were the only liquid-propellant vehicles launched from Wallops Island and were used for launching a variety of scientific experiments to gather information in the upper atmosphere, the ionosphere and space. This launch complex, currently inactive, is the prime candidate for refurbishment to support many of the commercial space activities planned in the future at Wallops Flight Facility.

(3) Launch Area Number 2 and Blockhouse Number 2 -Several types of launchers are located in this area since many types of vehicles carrying scientific experiments are launched from here. These include Nike-Cajun, Nike-Tomahawk, Orion, Nike-Orion and Black Brant sounding rockets as well as the small Arcas and Super Loki meteorological rockets.

(4) Launch Area Number 3 (Pads 3A and 3B) - Pad 3A is the pad from which the Scout vehicle has been launched in the past, and is located approximately one mile from the nearest waterway and 2 miles from the "public domain". It employs a horizontal type launcher which allows the vehicle to be prepared and held in the horizontal position until a short time before launch. At the proper time, the shelter building, which is mounted on steel tracks, is rolled away and the vehicle is elevated to launch position.

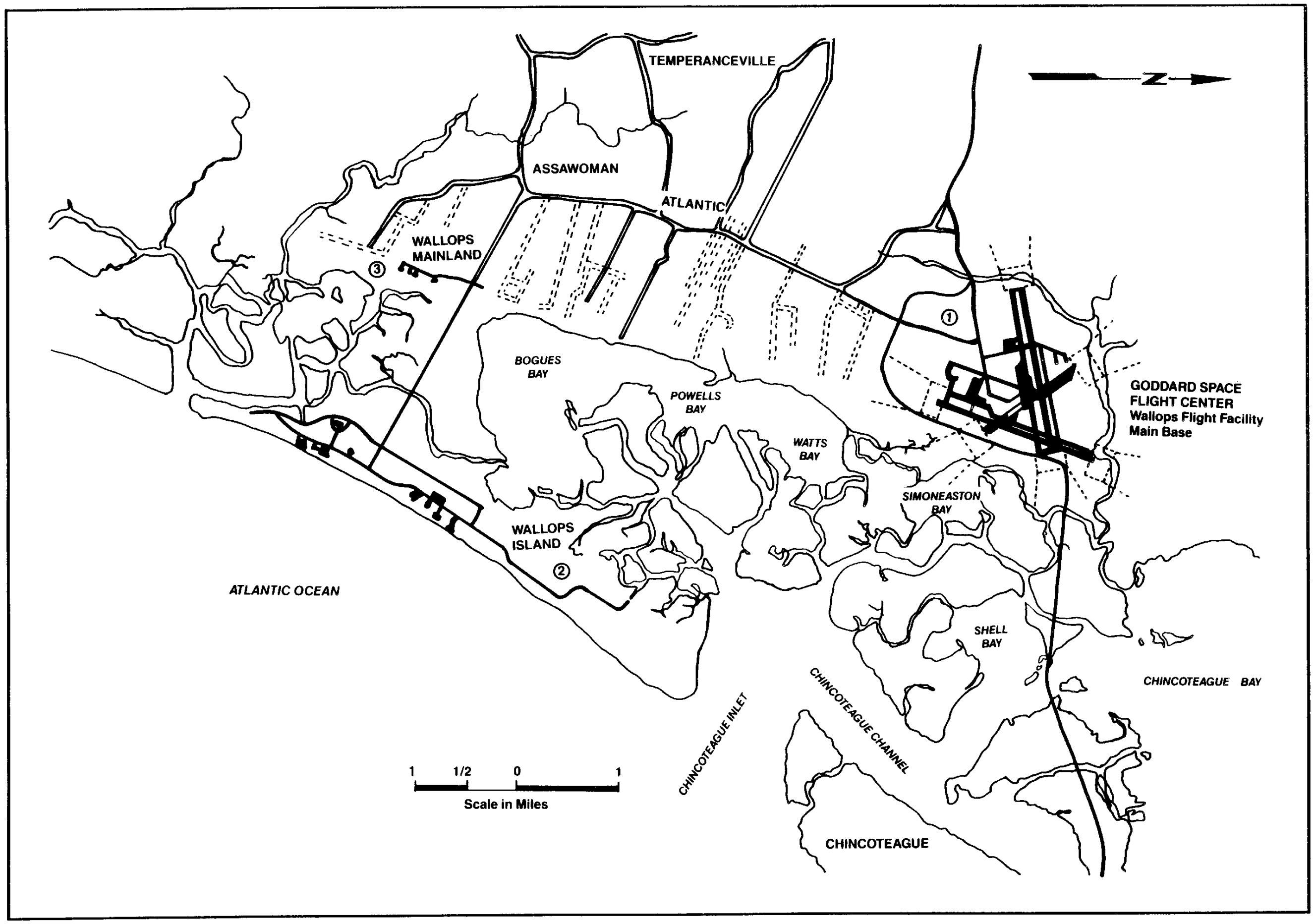
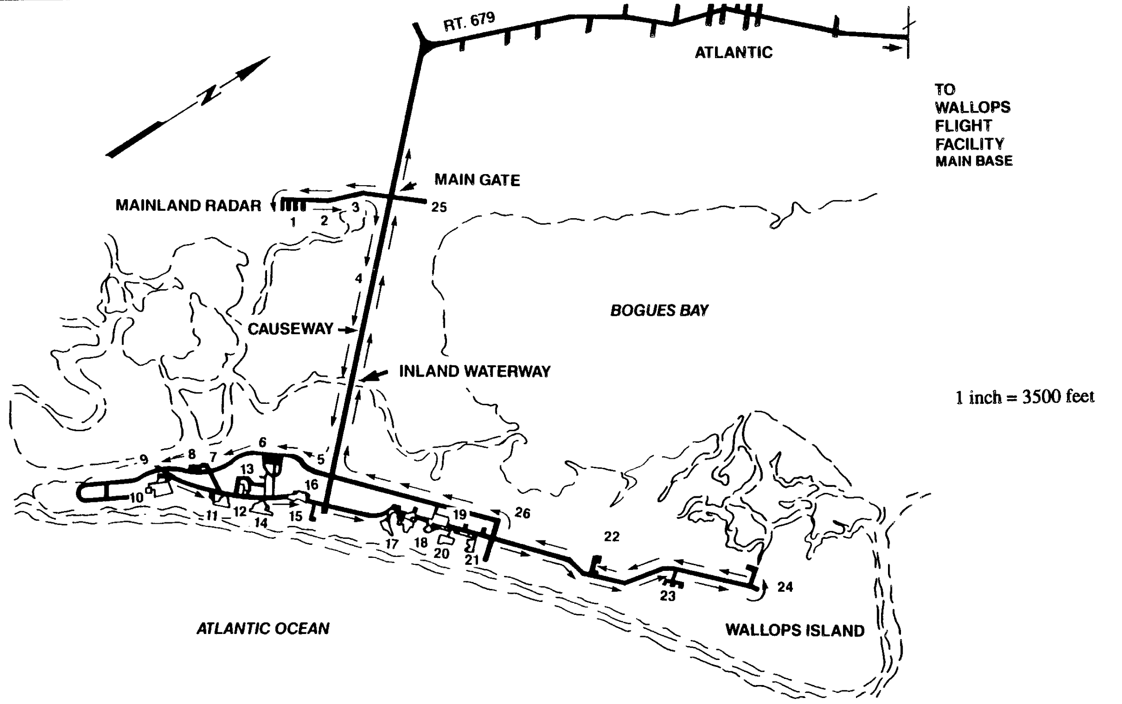


FIGURE 3. WALLOPS FLIGHT FACILITY



1 Radar Atmospheric Facility (RARF)
2 Atmospheric Physics Measurement Lab
3 FPQ-6 Radar
4 Causeway and Bridge
5 Meteorological Observation Center
6 Island Radar Site
7 Old Dock Area
8 Liquid Propellant Storage Area
9 Lagoon Sewage System
10 Launch Area No. 0
11 Launch Area No. 1
12 Assembly Shop No. 1
13 250-foot Meteorological Tower
14 Launch Area/Blockhouse No. 2
15 Technical Support Shop Area
16 Old Administration Building
17 Launch Area No. 3
18 Blockhouse No. 3
19 Launch Area No. 4
20 315-foot Meteorological Tower
21 Launch Area No. 5
22 Payload Checkout/Assembly Area
23 Dynamic Balance Facility
24 Old Coast Guard Station
25 Radio Transmitter Building
26 Aegis

FIGURE 4. WFF COMPLEX AND FACILITY LOCATIONS

Duplicate map located at end of report

The Scout is the largest vehicle that has been launched at Wallops and is capable of performing a variety of missions, including the launching of satellites, space probes and atmospheric re-entry tests. Pad 3B is used for some of the larger sounding rockets and special purpose missions. **Figure 5**[4] shows the layout of the Scout launch area. Near the launcher is the Assembly Shop where the first three stages of the Scout vehicle are built up, assembled on the transporter and tested prior to transport to the pad area. In a parallel operation, the payload undergoes preparation and test in the payload facility, is transported to the Dynamic Balancing Facility and mated to the fourth stage. After dynamic balancing is performed, the payload/fourth stage is transported to the pad area for mating with the vehicle.

(5) Blockhouse Number 3 - This concrete dome-shaped building north of Launch Area No. 3 is the blockhouse from which operations on Launch Areas 3, 4 and 5 are controlled. The walls of this building are 8 feet thick reinforced concrete.

(6) Launch Area Number 4 - This area is used for sounding rockets and special projects.

(7) Launch Area Number 5 - The Vandal missile is launched from here and is used as a target missile for off-shore Navy surface warship defense system tests. Vandal is a two-stage supersonic missile about 22 feet long and 30 inches in diameter.

(8) General Support Facilities/Areas - In addition to the above, there is an assembly shop where all the sounding rockets are assembled, checked out and prepared for launch, a payload checkout and assembly area where both inert and "hot" payloads are assembled and checked out and other support facilities and shops.[1]

b. Instrumentation

(1) Radar - Radar systems track sounding rockets, balloons, space vehicles, satellites and aircraft to provide accurate velocity and positional data. The range of support provided by radar systems at Wallops can vary from tracking local aircraft in the vicinity of Wallops airport to tracking distant objects in space. Radar capabilities can be enhanced by laser tracking systems and sophisticated data processing systems to improve the precision and to record, analyze and process radar data. Some Wallops Flight Facility aircraft are radar-equipped to support experiments and operations by providing range surveillance and tracking. The radars at WFF operate in the UHF, X, S and C frequency bands.

(2) Telemetry - Both digital and analog telemetry transmissions are used at WFF. Almost all systems operate with S-band (2200 to 2300 MHz) downlinks and the UHF band for uplinks. A frequency of 1680 MHz is used occasionally for down links on some of the smaller sounding rockets. Bi-phase Pulse Code Modulation/Frequency Modulation (PCM/FM) and FM/FM are the two basic systems employed.

Telemetry data systems have the capability of providing positional data for the target. There are two 24-foot automatic trackers and two 8-foot automatic trackers. These are supported by antenna control and receiving stations, four readout PCM stations, a digital PCM station and a meteorological station.

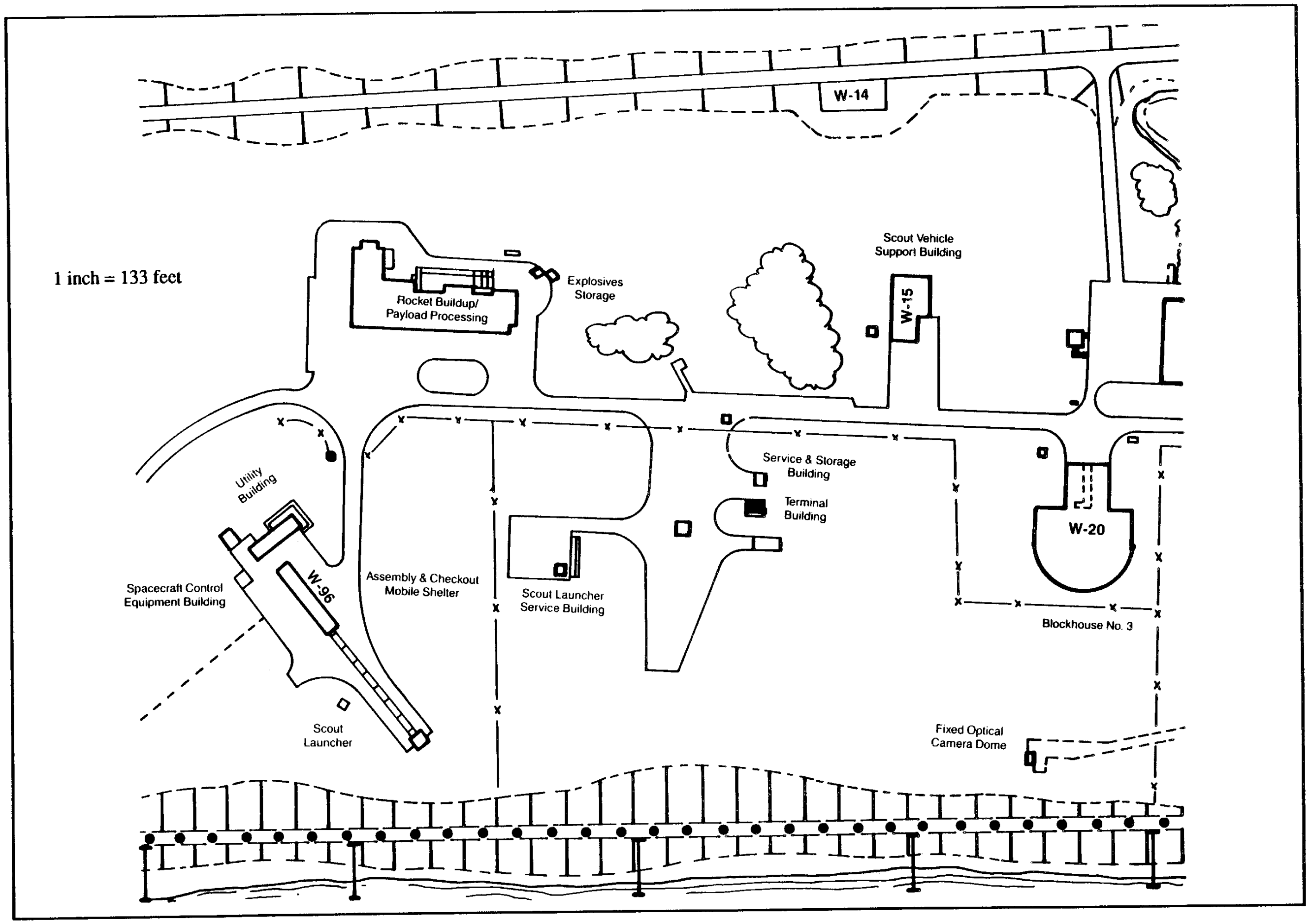


FIGURE 5. SCOUT LAUNCH AREA N0.3

(3) Data Systems - Data acquired during operations is processed by various computers at Wallops to provide information to experimenters and to support operations. A variety of data systems acquire, record and display information in real time for command, control and monitoring of flight performance.

(4) Communications - WFF operates ground-to-ground, air-to-ground, ship-to-shore and intra-station communications systems. These systems are composed of HF/VHF/UHF radios, cables, microwave links, closed-circuit television systems, command and control communications, frequency shift tone keying systems, operational teletype systems, high-speed data circuits and the WFF NASCOM Network terminal. Satellite communications and fiber optics are in growing use.

Communications provide the means for managing operations at Wallops and communicating and coordinating operations with related operations in other geographic areas (e.g. providing communications and tracking support for Space Shuttle operations at Kennedy Space Center).

(5) Command/Destruct - A Command/Destruct system allows ground control of airborne vehicle functions of on-board experimental devices. In addition, the Range Safety Officer (RSO) can terminate flight, in the event a malfunction presents a Range Safety hazard, of those vehicles equipped with a Flight Termination System.

(6) Optics - Remotely controlled television cameras monitor range operations and provide safety related information. Tracking cameras, including both film and a long-range video tracking system, provide visual information from remote locations for project and range support.

(7) Control Centers - There are two control centers at Wallops, located on the Main Base. The Airport Project Control Center controls experimental activities of aircraft using the Wallops Airport, and the Range Control Center controls launch, tracking and data acquisition operations. The control centers are focal points for communications, operational management and Range Safety. Vehicle operations, tracking and data acquisition are controlled and performance data is displayed on the Range Safety Display System and video monitors. Communications with all participants in a mission provide the means for coordinating complex operations.

B. RANGE CAPABILITIES ASSESSMENT

1. Mission Capabilities - The primary mission of the WFF Launch Range is to provide a safe and efficient site for NASA sounding rocket operations and to provide an east coast base for launching the NASA Scout rocket booster, an expendable launch vehicle used primarily to place small spacecraft into low earth-orbit. **Figure 6**[3] shows the allowable launch corridors for the Scout vehicle. Facilities on Wallops Island are used, as required, to support other NASA science and research programs, which may involve the use of small meteorological rockets or balloons to carry instruments to desired altitudes. In addition to support of NASA programs, the Launch Range is utilized for rocket and non-rocket programs of other U.S. Government agencies, where such use does not impact on the NASA sponsored activities. Typical other-agency programs supported include: VANDAL, a high speed target missile, for the Naval Air Test Center; sounding rockets for the Air Force Geophysics Laboratory; and full scale aircraft development programs for the Naval Air Test Center.[1]

2. Instrumentation Capabilities - Tracking and data acquisition activities at Wallops are covered by three functional areas: radar, telemetry and data systems, including communications and optics. These activities support the full range of sounding rocket, balloon and aeronautical research and development and scientific experimentation. Similar capabilities can be configured to support mobile operations worldwide. In addition, WFF has a satellite tracking facility as an integral part of the station telemetry capability.

a. Radar Systems[5] - The WFF radar system capabilities are shown in **Table 3**[5].

(1) AN/FPQ-6 - The AN/FPQ-6 is a C-band, monopulse tracking radar designed and built for precision long-range tracking. It is frequently referred to as a Missile Precision Instrumentation Radar (MIPIR).

At WFF, this radar is used primarily to provide launch vehicles position and velocity data in real time. It is capable of providing continuous, accurate spherical-coordinate information on cooperative targets out to a range of 37,000 miles.

During operation, the radar antenna will automatically track (skin or transponder) a launch vehicle or other airborne targets with a minimum of tracking jitter or bias. The radar is located on Wallops Mainland.

(2) AN/FPS-16 - One of two AN/FPS-16 radars at WFF is located on Wallops Island and is used primarily to provide rocket, balloon and satellite position data. It is a high precision, C-band, monopulse tracking radar and is capable of providing continuous, accurate spherical-coordinate information on targets out to a range of 37,000 statute miles. It will skin or transponder track and automatically follow a space or airborne target.

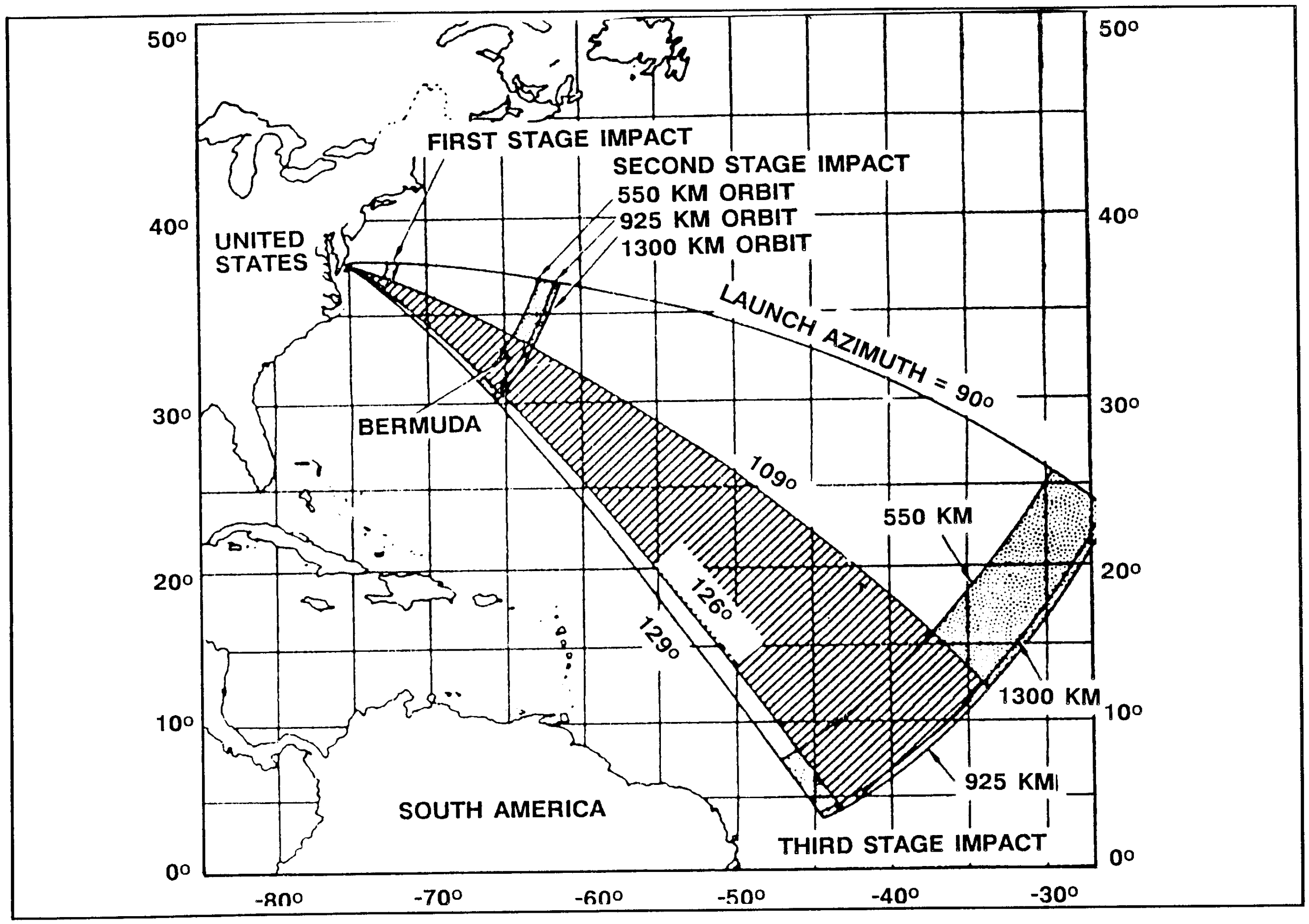


FIGURE 6. WFF ALLOWABLE LAUNCH CORRIDORS

TABLE 3. RADAR SYSTEM CAPABILITIES

RADAR	WAVE LENGTH BAND	PEAK POWER OUTPUT (WATTS)	PULSE RATE FREQUENCY (PPS)	BEAM WIDTH	ANTENNA DIAMETER (METERS)	ANTENNA GAIN (DB)	MAX RANGE (KM)	1-M² SKIN TRACK (KM)	RANGE PRECISION (METERS)	ANGLE PRECISION (MIL RMS)	SLEWING RATE (DEG/SEC) AZ EL
ASRF	UHF S	8M 5M	320-960 160,320,640,960	2.9 0.39	18.29 18.29	36 52.8	N/A 480K	1480 2200	N/A ±5	±2.0 ±1.0	8 8 15 15
AN/MPS-19	S	325K	160,320,640,1280	3.0	2.44	33	925	100	±10KMS	±1.0	60 60
AN/ASR-7	S	425K	713,1200,OTHERS AVAILABLE	1.5(AZ) CSC(EL)	5.33X 2.74	34	110	75 AIRCRAFT	±1%	N/A	N/A N/A
VERLORT	S	250K	410,512,585	2.53	3.05	37	4200	110	±25	±0.5	50 50
AN/FPQ-6	C	3M	160,640,OTHERS AVAILABLE	0.39	8.84	51	60K	1300	±3RMS	±0.05	28 28
AN/FPS-16 (ISLAND)	C	1M	160,640,OTHERS AVAILABLE	1.23	3.66	43	60K	350	±3RMS	±0.1	45 28
AN/FPS-16V AIRPORT RADAR LASER	C INFRA	1M 2.5M	160,640,1024 40	0.71 0.11	4.88 0.18	46 N/A	60K 40	435 N/A	+3.0 ±0.5	+0.1 ±0.1	45 25 N/A N/A
RIR-778C (MOBILE)	C	1M	160,320,640	1.5(ACQ) 3.0(TRK)	2.38	38	3745	220	0.87204	0.2441	40 40
MARINERS #1 PATHFIND	X	40K	1000,4000	9.6@3db (H)	3.67X 0.15	30	175	28 SHIPS	N/A	N/A	N/A N/A
AN/APS-80BV	X	200K	400	2.4(H) 3.6(V)	1.18X0.81	35	155	N/A	N/A	N/A	N/A N/A
AN/APS-128E	X	100K	267,400,1200,1600	2.4(AZ) 9.0(V)	1.06X 0.305	31	125	N/A	±1% MAX RANGE	N/A	N/A N/A
RIR-778Ka	Ka	135K	320,640,1280	0.5(NOM)	2.38	54	468	80	0.4360	0.2441	40 40

(3) RIR-778C - There are three Range Instrumentation Radar (RIR) 778C radar systems at WFF. All are mobile C-Band precision computer based RF and optical tracking systems designed and built to obtain continuous and highly accurate positional data of various airborne targets for flight test programs. The RIR-778C is a mobile unit capable of conducting world wide missions. The system is capable of providing continuous, accurate, spherical-coordinate information on targets out to ranges of 2340 miles. It is capable of both skin and transponder tracking. The system will provide and record trajectory data in real time for future evaluation.

(4) AN/MPS-19 - WFF has one permanently installed AN/MPS-19 radar located on top of the Island Control Center on Wallops Island. This modified, narrow pulse, S-band tracking radar is used primarily for early acquisition of rockets and for weather balloon tracking. The AN/MPS-19 radar system is capable of acquiring and providing continuous automatic tracking of skin or transpond targets. A radar transponder is necessary to obtain maximum tracking range. As an early acquisition radar, the AN/MPS-19 provides azimuth and elevation data on the target being tracked to other WFF radars to aid them in acquiring the target.

(5) Mariners Pathfinder - The Mariners Pathfinder is an X-band search radar, Model 1605, used primarily to detect shipping that might be endangered by rocket firing at WFF. A movable range mark permits accurate ranging to any point 0.25 to 20 miles with an accuracy of 1%. Channel markers and buoys can be seen on fairly rough waters up to 2.8 miles and sometimes as far as 6.2 miles. This radar is located on Wallops Island.

(6) AN/APS-80B(V) Airborne Search Radar System -This radar was designed to perform range surveillance and is installed on one Lockheed Orion NP-3A aircraft (other aircraft are also used for airborne surveillance) stationed at WFF. It is used to locate ships or aircraft on the WFF test range. It can provide surveillance through a continuous 210 degrees in azimuth of a 45 degree sector scan. During ideal clear weather conditions, maximum range of the radar is 96 miles at the maximum altitude of 30,000 feet.

(7) AN/APS-128(E) Airborne Search Radar System -This radar is a high-powered airborne surveillance radar system designed for detection and surveillance of both airborne and surface seaborne targets. It is primarily used to locate ships that are operating on the WFF test range. The radar antenna is mounted in the belly of a Skyvan aircraft and scans 360 degrees as it searches for radar targets. During ideal clear weather conditions, maximum range of the radar is 230 miles. This set can be used as high as 16,000 feet.[5] See **Figure 7**[5] for a typical radar system block diagram.

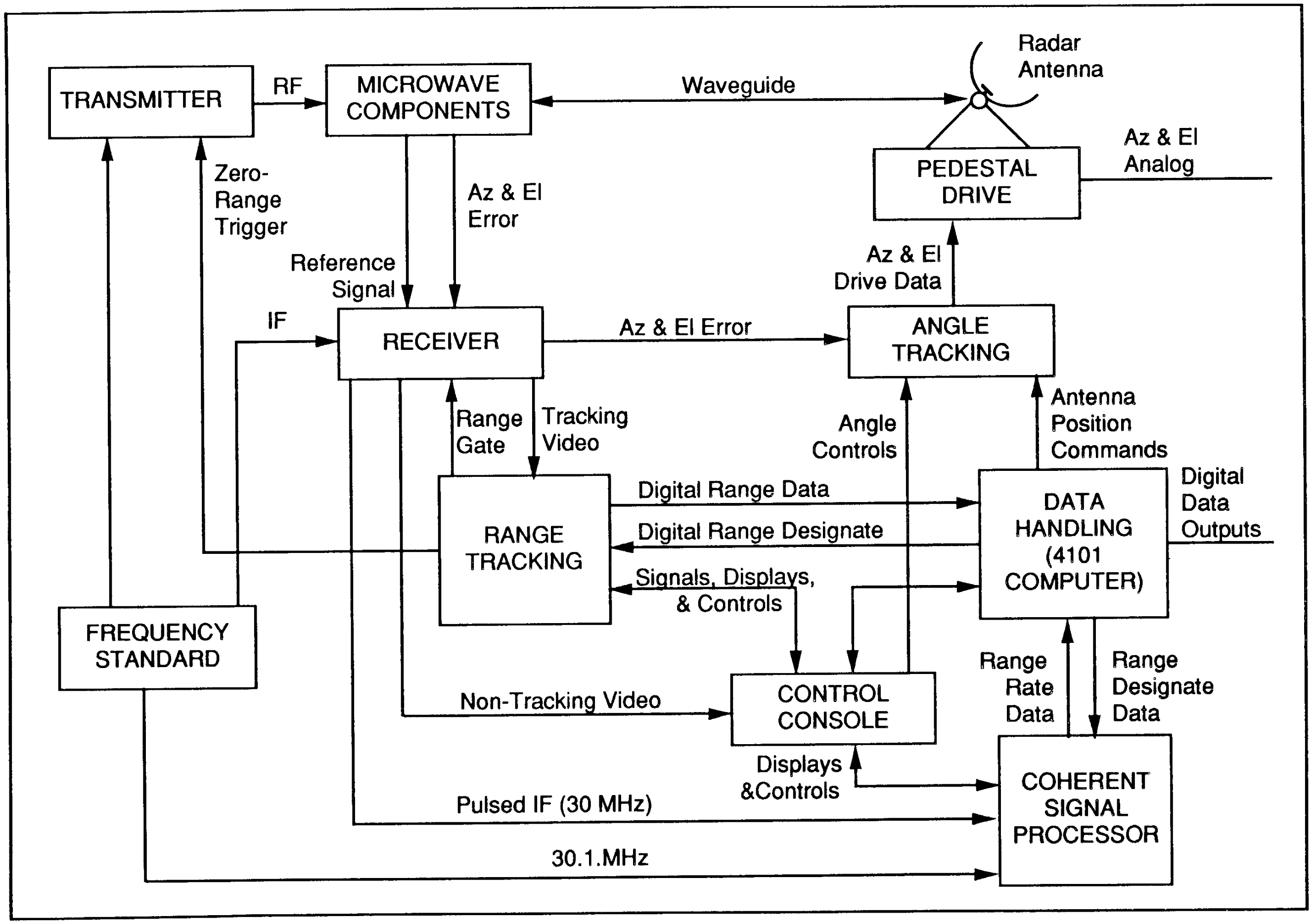


FIGURE 7. TYPICAL RADAR SYSTEM BLOCK DIAGRAM

(8) Radar Data Acquisition and Display Systems -There are three systems at WFF for radar data acquisition and display. They are the Radar Tracking System Target Acquisition and Display System (RATSTADS), the Space Vehicle Radar Target Acquisition System (STAR) and the Radar Data Graphics Display System (RDGDS). Each performs some of the following functions:

- Provide the means of remotely displaying the position of the radar target
- Allow all radars to slave their antennas to whichever radar has the target
- Ability to slave the command/destruct and telemetry antennas to the target
- Ability to slave WFF radars to a target acquired by radars not at WFF (e.g., KSC radars).

Five radars at WFF: two on Wallops Island, two on Wallops Mainland and one at the WFF airport on the Main Base, support these functions.[6]

b. Optic Systems - Wallops' photographic capabilities can provide complete documentation of any given rocket launch sequence, including medium-and high-speed tracking coverage of the vehicle flight, sequential coverage of the vehicle lift-off, intermittent and close-up studies of vehicle motor operation, documentary coverage of the vehicle assembly and still photographs of the vehicle in the horizontal and elevated positions on the launcher.

The flight of the vehicle is photographed by cameras on short range optical trackers (SOT) and intermediate focal length trackers (IFLOT). There are 2 fixed SOT's, 1 mobile SOT, 1 fixed IFLOT and 5 mobile IFLOT's. The fixed SOT's and IFLOT are housed in astrodomes on top of 25-foot towers. Eachtracking station is equipped with a voice communication system and 36-bit time code signals. When a SOT or IFLOT is installed in an astrodome, a servo drive system synchronizes the dome with the tracker. The IFLOT mounts are electro-hydraulically driven in azimuth and elevation and are operated by one man.[7]

c. Telemetry Systems - Wallops has ten independently controlled telemetry antenna systems. Seven are trailer-mounted transportable antennas and three are components of the following fixed systems: One Advanced Data Acquisition System (ADAS) and two Medium Gain Telemetry Acquisition Systems (MGTAS). All of these systems offer closed loop spatial tracking by sensing an RF signal radiated from the vehicle.

Where experiments employ multiple RF carriers, selection of a carrier for tracking purposes is a User's option, since it does not impinge on the reception of telemetry data. The fixed receiver system offers the User a high degree of flexibility and redundancy. Each of two identical systems contains six receivers with plug-in RF heads to cover the appropriate frequency band.

NASA offers several transportable telemetry systems designed to provide temporary coverage at locations beyond that served by fixed facilities at Wallops.[9] **Figure 8**[9] shows a typical telemetry system block diagram.

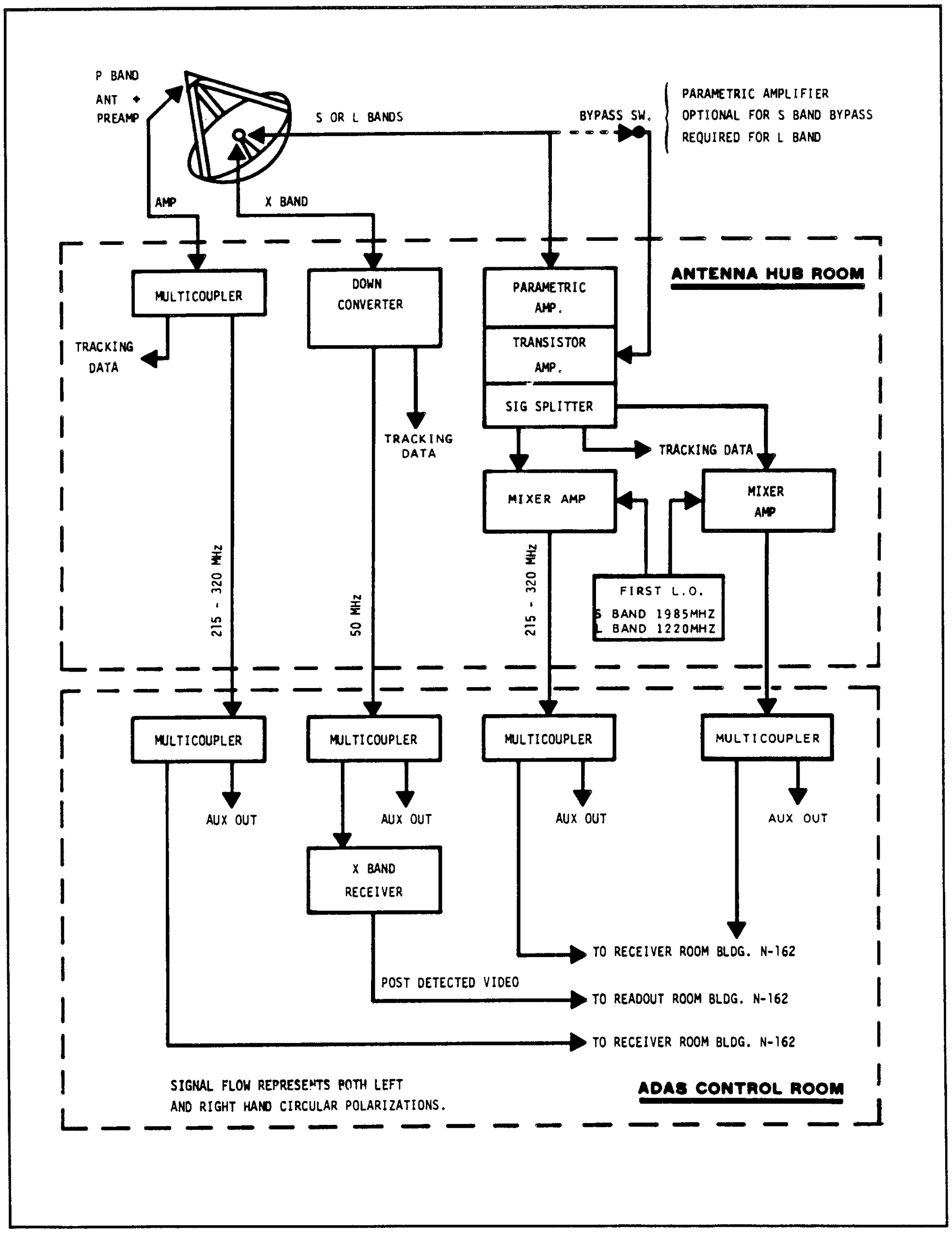


FIGURE 8. TYPICAL TELEMETRY SYSTEM BLOCK DIAGRAM

d. Communications Systems$_{10}$ - The communications systems outlined in paragraph **A.3.b.(4)** are located at Wallops Island, Wallops Mainland and Wallops Main Base, at remote stations and mounted in vans for downrange and shipboard use. RF support services include spectrum management, frequency monitoring and interference control, search, recovery and homing systems and meteorological information systems.

The Communications Receiver Facility is located on the Main Base in the Telecommunication Building, which houses the receivers, recorders, patching panels, command/destruct monitors and recorders and the supporting ancillary equipment.

The receiving antennas are mounted on towers and poles in the immediate area. World-wide reception is possible. The Frequency Monitoring and Interference Control facilities are collocated with the Communications Receiver Facility.

The Communications Transmitter Building is located on the Mainland and the transmitting antennas are mounted on top of the building and on towers and poles in the immediate area. An alternating current power generator for the redundant command/destruct and communications system is located in an adjacent building at this facility. World-wide transmission is possible.

The mobile facilities are defined as those mobile systems housed in vans which can be moved from place to place on the station, moved downrange or placed aboard ship.

These systems include the Mobile Command/Destruct System and the Mobile Closed-Circuit Television System.

e. Command/Destruct System$_{10}$ - The Command/Destruct Systems at Wallops provide ground control of certain rocket and payload functions for flight safety and/or other command purposes. The Range User can use these systems to command payload functions as necessary, within range limitations.

(1) Ground Transmitters and Antennas

(a) Fixed Command/Destruct System - Each permanent system consists of two Radio Transmitting Sets with Quad-helix antennas. Each transmitter has a minimum RF power output of 1000 watts in the frequency range of 406.0 to 549.0 MHz. The RF carrier is frequency modulated by certain pre-selected tones that correspond to particular functions that are to be performed on the rocket or payload. The carrier frequency is normally set at 412 MHz; however, other frequencies can be used if required for special cases, i.e., 416.5 MHz when being used in support of a launch from the Eastern Test Range, 447 MHz for vehicle commands and 425 MHz for drone vehicles. In addition, IRIG tone 7 is sometimes used to replace tone 5 when WSMR receivers are being used. The transmitted signals are monitored and recorded at the Transmitter Building by a receiver-audio decoder combination. There are three Command/Destruct Systems available at Wallops, two fixed systems located on the Mainland and a Mobile System. These systems work in conjunction with the Bermuda Command/Destruct system when

required.
The fixed system consists of two subsystems connected in a fail-over arrangement. If the primary subsystem fails, or if the RF power output falls below a predetermined level, fail-over is automatically initiated. The redundant subsystem then assumes control of the Command/Destruct function.
(b) Primary Command/Destruct Subsystem - The Primary Command/Destruct Subsystem consists of an ALEPH CTS-100 Transmitting Set, an ANTLAB Quad-helix antenna and the necessary control circuits.
The transmitter modulation can by controlled locally, or by remote control from the Range Control Center. The transmitter and antenna pedestal operate from commercial AC power. The primary antenna is slaved, by means of the radar data acquisition bus, to a radar selected to provide the most accurate position information on the rocket/payload being tracked.
The RSO can remotely control certain functions of the rocket or payload such as the arming and destruction of a rocket, or specific rocket or payload mission commands that may be required. System status and verification indications are provided to the RSO. **Figure 9**[10] shows a typical block diagram of a command system.
(c) Redundant Command/Destruct System - The Redundant Command/Destruct Subsystem (identical to the primary) is powered by a local generator so that, in case of a failure of commercial power during a mission, control will still be maintained over the rocket/payload. The Quad-helix antenna used with this subsystem is positioned manually using predetermined angle versus time information.
(d) Mobile Command/Destruct System - The Mobile Command/Destruct System consists of two Collins AN/FRW-2A Radio Transmitting Sets and associated equipment mounted in a mobile van. Each transmitter has a minimum RF power output of 500 watts in the frequency range of 406.0 to 549.0 MHz. The equipment is connected in a fail-over arrangement and can be used downrange for prime operation or as a backup system in support of the Wallops Mainland system. A small, manually pointed, crossed-dipole antenna is used as a spare. Transmitter modulation can be controlled locally.
(e) Digital Range Safety Command Set - The Digital Range Safety Command Set was designed to operate in conjunction with the Eastern Test Range for Command/Destruct control of launches by Kennedy Space Center during Shuttle operations.

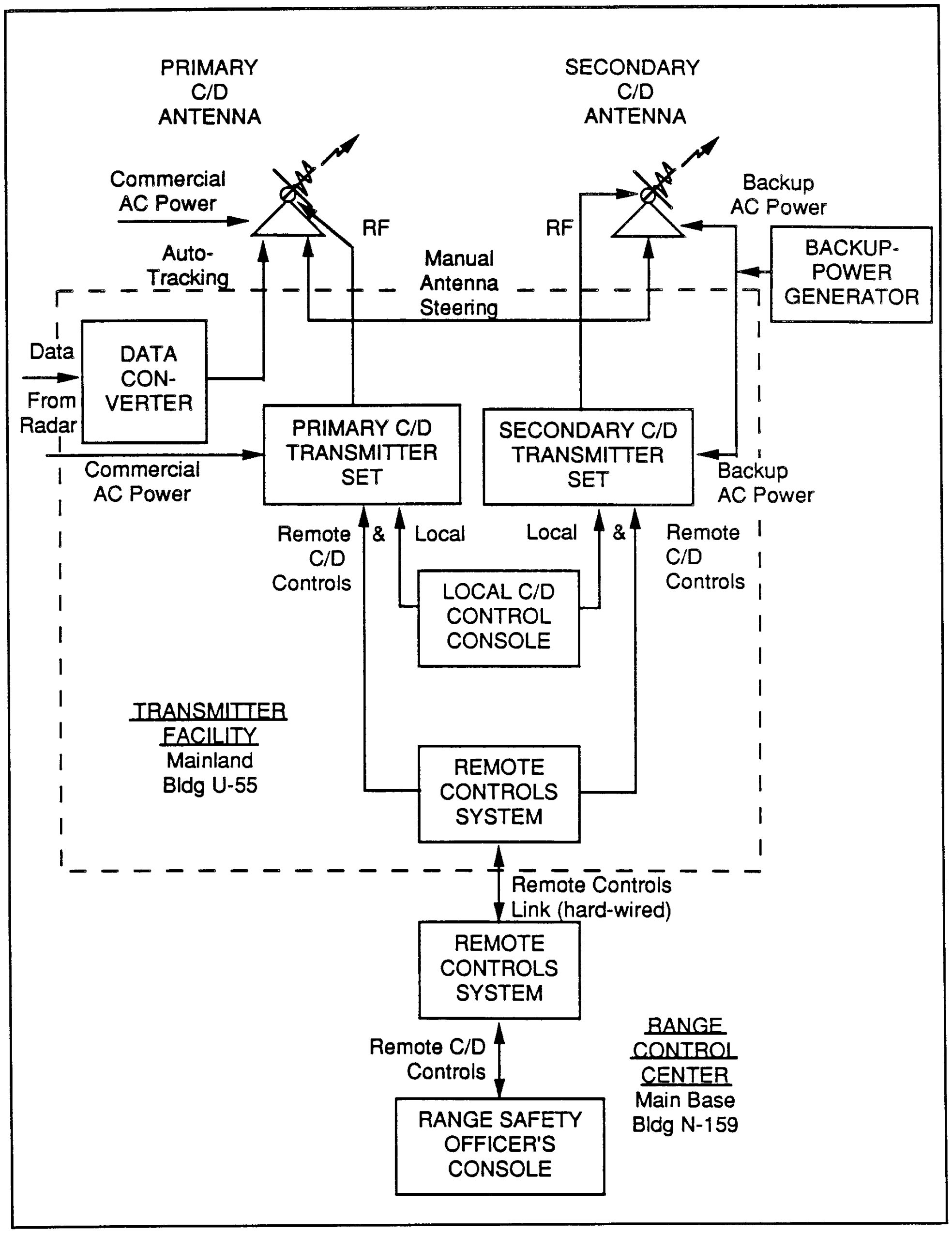


FIGURE 9. TYPICAL COMMAND SYSTEM BLOCK DIAGRAM

(2) Launch Vehicle Flight Termination System (FTS)

(a) Design - If it is determined by the WFF Range Safety personnel that a Flight Termination System is required, a system must be employed whereby thrust may be terminated, stage ignition prevented or delayed, or other means employed to insure that the impact and overflight criteria are not exceeded. A preliminary design of a vehicle FTS must be submitted to the Ground and Flight Safety Section by the Range User for analysis and approval.

For the majority of rocket vehicles flown from WFF that require flight termination systems, WFF Range Safety furnishes A.R.F. 9B, 4-channel command receivers. If the Range User elects to provide his own receivers, they must meet the minimum command receiver/decoder specifications as described in the WFF Range Safety Handbook.

(b) Operation - The standard flight termination scheme is to frequency modulate the carrier with three audio tones to effect "ARM" (fuel cut-off/shutdown for liquid propellant engines) and "DESTRUCT". The audio tones are standard at all ranges and were established by the Inter Range Instrumentation Group (IRIG). Normally, tones 1 and 5 are transmitted as the "ARM" command. This cuts off thrust to a liquid fueled booster and conditions the airborne receiver logic to receive and act upon a "DESTRUCT" command. "DESTRUCT" will not be acted upon unless preceded by "ARM". Tone 1 is kept on, tone 5 removed and tone 2 added to effect "DESTRUCT".[3]

C. COMMERCIAL LAUNCH VEHICLE INFORMATION AND DESCRIPTION - The characteristics of launch vehicles are as follows:

1. The Scout Launch Vehicle

a. Description - The normal configuration of the Scout launch vehicle is a four-stage, solid propellant vehicle which is made up of the Algol III-A first-stage motor, the Castor II-A second-stage motor, the Antares III-A third-stage motor and the Altair III-A fourth-stage motor. It is 3.7 feet in diameter, is approximately 75 feet tall and weighs 47,200 pounds at lift-off. It develops 107,000 pounds of thrust at lift-off and is capable of placing 400 pound payloads into a 345 statute mile orbit.[11] See **Figure 10**[8] for a typical Scout vehicle.

b. Hazards - The primary hazards of this launch vehicle during preparation and launch are scattered pieces of burning propellant resulting from a pressure rupture of the separate stages and any toxic propellants that may be associated with the spacecraft; i.e., Hydrazine (N_2H_4).[12] WFF provides the special suits, breathing apparatus, leak detection equipment and laboratory quality analysis support required for handling the hydrazine. Detailed procedures for fueling the propellant servicing unit and the spacecraft have been established and approved by the appropriate safety organizations and documented in the Ground Safety Plan.[13] After lift-off, the additional hazards of impacting stages and missile parts as well as possible detonation of stages upon impact must be considered.

c. Trajectory - Except for special cases, the Scout is launched on azimuths of 90^0 to 109^0 and 126^0 to 129^0. It clears the Wallops Island land mass in approximately 5 seconds. Launch in the corridor of 109^0 to 126^0 is not normally allowed due to the close proximity of Bermuda to the second stage impact point; however, exceptions have been made when Range Safety criteria could be satisfied.

d. In-Flight Events - The sequence of in-flight events for a typical mission is shown in **Table 4.**[8]

TABLE 4. SCOUT NOMINAL SEQUENCE OF EVENTS

EVENT	TIME (SEC)	EVENT	TIME (SEC)
LAUNCH	T+0	ST III IGNITION	T+199
ST I BURNOUT	T+85	ST II SEP	T+199
ST II IGNITION	T+88	ST III BURNOUT	T+246
ST I SEP	T+88	ST IV SPINUP	T+586
ST II BURNOUT	T+128	ST IV IGNITION	T+592
HS EJECT	T+197	ST IV BURNOUT	T+625

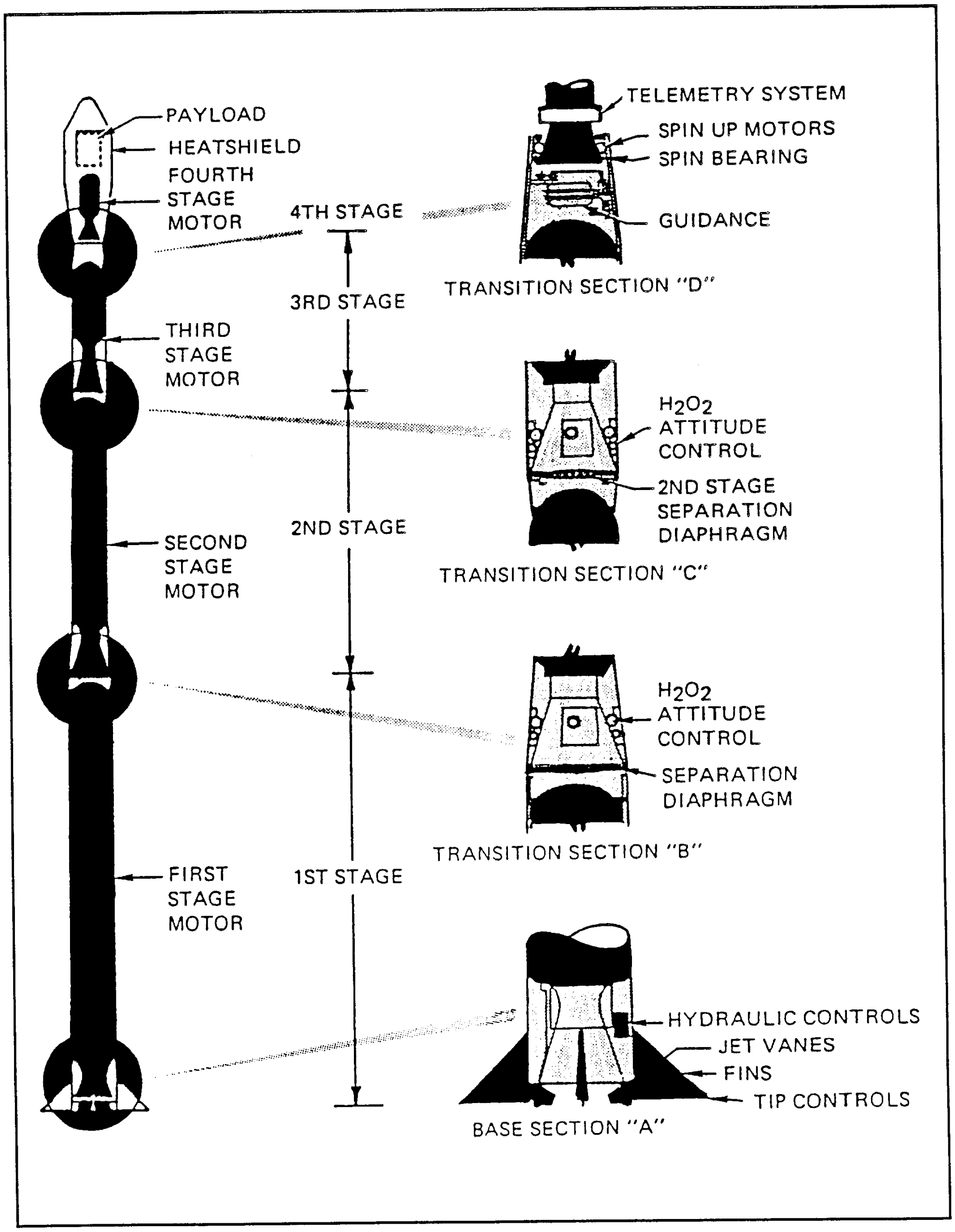


FIGURE 10. TYPICAL SCOUT VEHICLE

e. Airborne FTS - The FTS consists of two antenna pairs, two receivers and one Destruct Relay Unit mounted on the third stage, with Safe and Arm (S/A) devices and shaped charges on each of the first three stages. Inadvertent Separation Destruct Systems (ISDS) are located on the first and second stages. The fourth and fifth (if applicable) stages do not have destruct systems; however, if the destruct command is sent, the third stage shaped charges destroy the fourth stage ignition wiring and fifth stage ignition cannot occur unless there is a pressure buildup in the fourth stage motor. Therefore, all stages are either destroyed or rendered non-propulsive.[14]

2. Sounding Rockets - Sounding rockets are used to fill the gap between the maximum altitude for balloons (about 30 miles) and the minimum altitude for satellites (about 100 miles). In addition, they are very useful to overlap the satellite space. Experiments flown on sounding rockets provide a variety of information, including high altitude wind shear and velocity measurements, density and temperature of particles in the upper atmosphere, properties and changes in the ionosphere, measurements of the brightness of stars and natural radiation surrounding the earth, characteristics of the ionization phenomena as space vehicles reenter the atmosphere and many other phenomena of earth's environment.[15]

Fifteen different launch vehicle systems are currently used by NASA to provide the performance requirements necessitated by various experiments with diverse weight and altitude requirements, with a launch rate of 30 to 35 launches each year.

Figures 11[1] and **12**[2] show the typical sounding rocket vehicles in the NASA inventory and their performance capabilities. It should be noted that these vehicles are not necessarily available for commercial use.

Approximately 2,500 NASA sounding rocket missions have been conducted since 1959 with an 86% mission success rate for that period, and a 96% mission success rate for over 142 missions in the last five years.[15,16]

a. Description - Currently, the Black Brant X, a Terrier, Black Brant, Nihka motor configuration provides the greatest performance of the sounding rockets. The Black Brant X can boost a 300 pound payload, launched at an 82 degree elevation angle, to a 453 nautical mile apogee altitude.[17] However, due to increasing requests from the scientific community, the National Aeronautics and Space Administration has developed a new sounding rocket vehicle system which, to date, has undergone one test flight. This system, named the Black Brant XII, offers increased performance over existing sounding rockets. The same payload and launch conditions on a Black Brant XII yields an 807 nm apogee altitude. The Black Brant XII is a four stage configuration composed of a Talos, Taurus, Black Brant, Nihka motor combination.[1]

b. Hazards - The hazards associated with sounding rockets are those associated with any solid rocket motors: they may generate intense heat, if ignited, become a missile or, if subjected to severe impact forces, explode. Generally, the most likely hazard is fire caused by burning debris from a case rupture. Explosions are normally limited to vehicles impacting the Earth at relatively high velocities (over 300 feet per second).

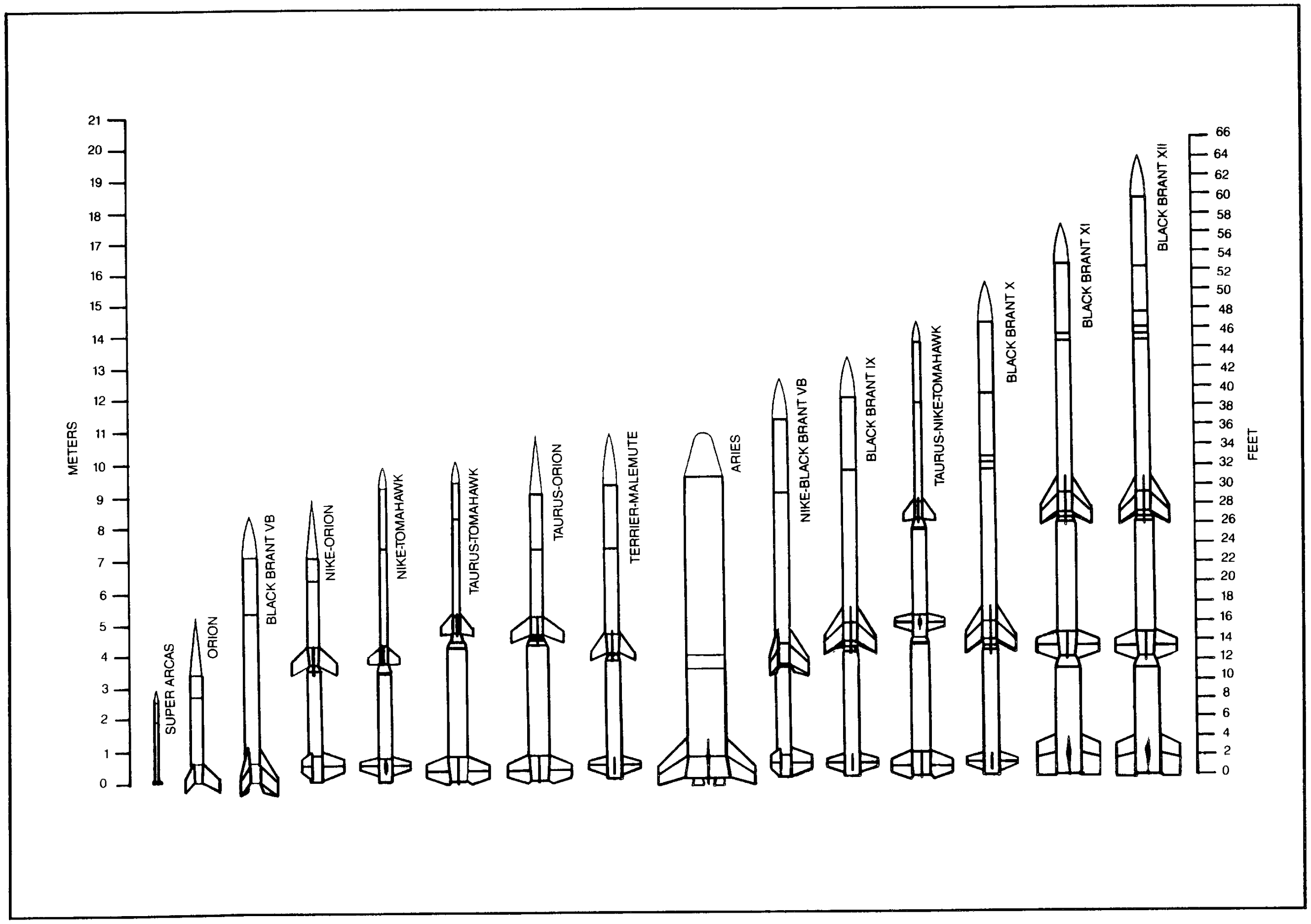


FIGURE 11. TYPICAL WFF SOUNDING ROCKET VEHICLES

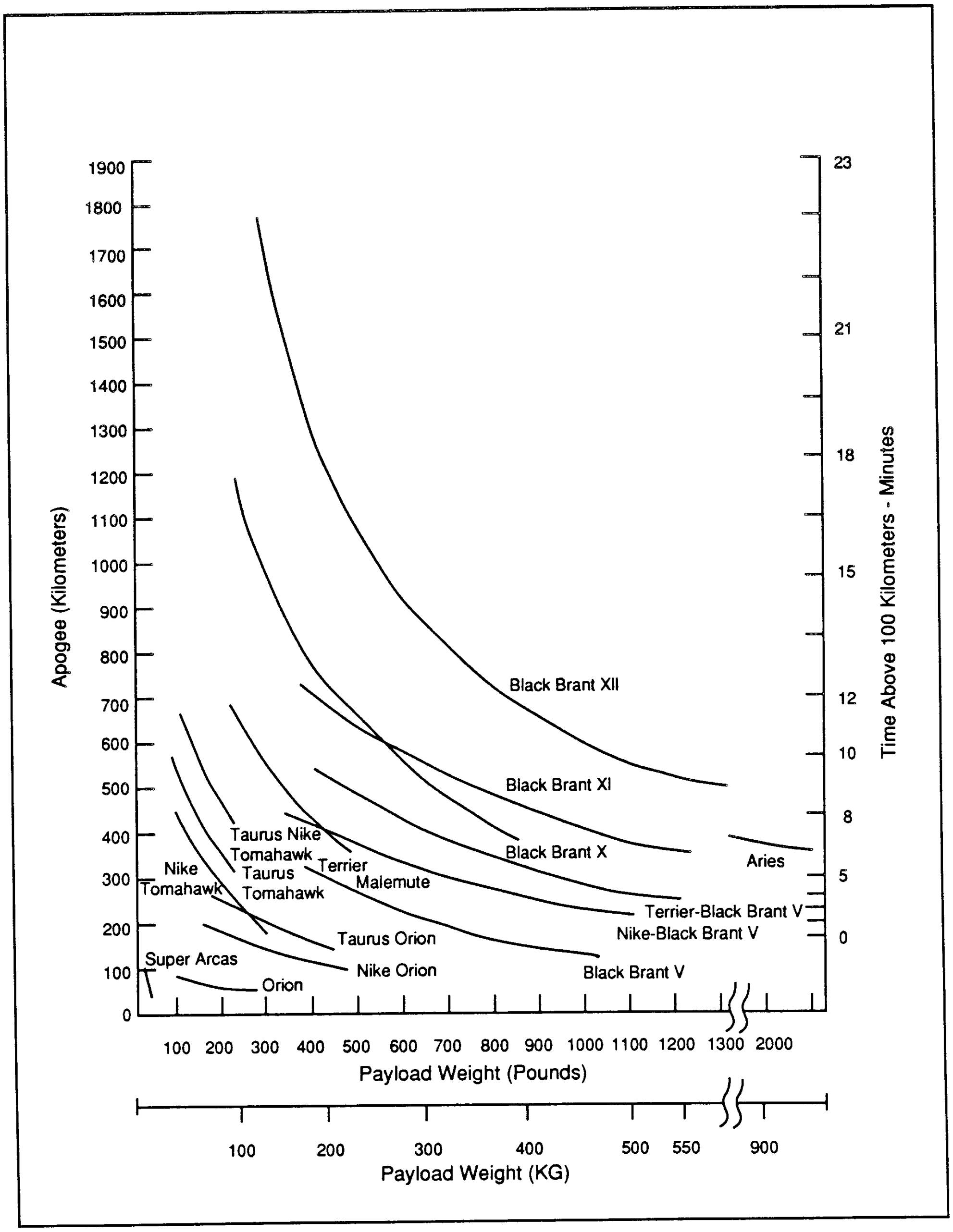


FIGURE 12. NASA SOUNDING ROCKET PERFORMANCE

c. Trajectories - Sounding rockets fly on azimuths of approximately 90^0-165^0 and elevation angles as follows:

- Vehicles flown for the first time - 80^0
- Proven flight-worthy vehicles - 84^0
- Vehicles with a flight termination system - >84^0

These trajectories carry scientific instruments to heights of from 40 to several hundred miles above the Earth's surface. Their effective lifetime is usually only a few minutes since they follow a trajectory back to Earth. The scientific data is collected and usually returned to Earth by a radio link. Parachutes are sometimes used to increase the experiment time and/or to recover the instruments for reuse.[2] See **Figure 13**[1] for a typical sounding rocket mission profile.

d. In-flight Events - Sounding rocket launch vehicles carry research payloads with scientific instruments to altitudes ranging from thirty miles to maximum altitudes of approximately 600 miles. The experiment time above the Earth's atmosphere ranges up to 15 minutes. Scientific data are collected and usually returned to Earth by telemetry links. **Table 5**[16] shows the event times for a Black Brant X sounding rocket. There are three types of payload recovery systems used by WFF at their various launch site locations: Land, Water and Air; however, land recovery is not used for vehicles launched at the Wallops Island Facility. Generally, the recovery systems contain two totally independent circuits for logic redundancy. Each circuit includes a "5g" timer, capacitor powerpack, safe/arm relay and a 20,000 feet baroswitch. In addition, for water recovery, the system contains flotation gear and location aids. For air recovery, the only onboard recovery equipment is a reinforced parachute which is snatched from the air by recovery aircraft.

TABLE 5. BLACK BRANT X NOMINAL SEQUENCE OF EVENTS

EVENT	TIME (SEC)	EVENT	TIME (SEC)
Terrier Ignition (First Stage)	T+0	Black Brant Separation	T+88.0
Terrier Burnout (First Stage)	T+4.4	Nihka Ignition (Third Stage)	T+93.0
Black Brant Ignition (Second Stage)	T+12.0	Nihka Burnout (Third Stage)	T+111.0
Black Brant Burnout (Second Stage)	T+44.4	Nose Cone Eject	T+115.0

e. Airborne FTS - Inherent safety for a sounding rocket is determined by probability estimates based on known system errors and a set of qualifying conditions as stated in paragraph **D.1.b.** and, in addition, the vehicle must be designed using state-of-the-art techniques that have been proven to be highly reliable by flight tests or otherwise proven flightworthy. If a sounding rocket cannot satisfy this set of conditions, a flight termination system that meets Range Safety requirements must be employed.

The requirements for using a flight termination system can be found in Section 6, Flight Safety of the GHB 1771.1.[18] Three types of flight termination systems are used for sounding rockets at the Wallops launch range: 1) fuel cut-off, 2) command destruct, and 3) ignition inhibit.

The fuel cut-off system closes valves which stops flow of the fuel and oxidizer to the thrust chamber, thereby terminating thrust. However, liquid propellant systems have not been flown from Wallops launch facility in the past 20 years.

Command destruct is the most widely used type of flight termination system at Wallops. In this system, an electroexplosive device in the vehicle is initiated when the destruct command is sent which ruptures the motor case, thus terminating thrust.

In the ignition inhibit type of flight termination system, the command to inhibit ignition is sent before the rocket motor ignites. This type of flight termination is used on vehicles that requires a flight termination system and when there is sufficient confidence that the vehicle will impact within safe limits. A gain in vehicle performance, due to less weight, is realized when using this system.

In all cases, flight termination is initiated from the ground (the control center) by the Range Safety Officer (RSO). This command is transmitted by one of the three command transmitters used by the Wallops range. Typical Sounding Rockets with flight termination systems that were flown from the Wallops range include the AEROBEE (in the 1960's), ATHENA (in the 1970's), BLACK BRANT V, BLACK BRANT X and BLACK BRANT XII (all still in the current inventory). Also, a new vehicle referred to as the TALOS/ARIES is planned to be launched from the Wallops range (FY90) and will be required to carry a flight termination system.

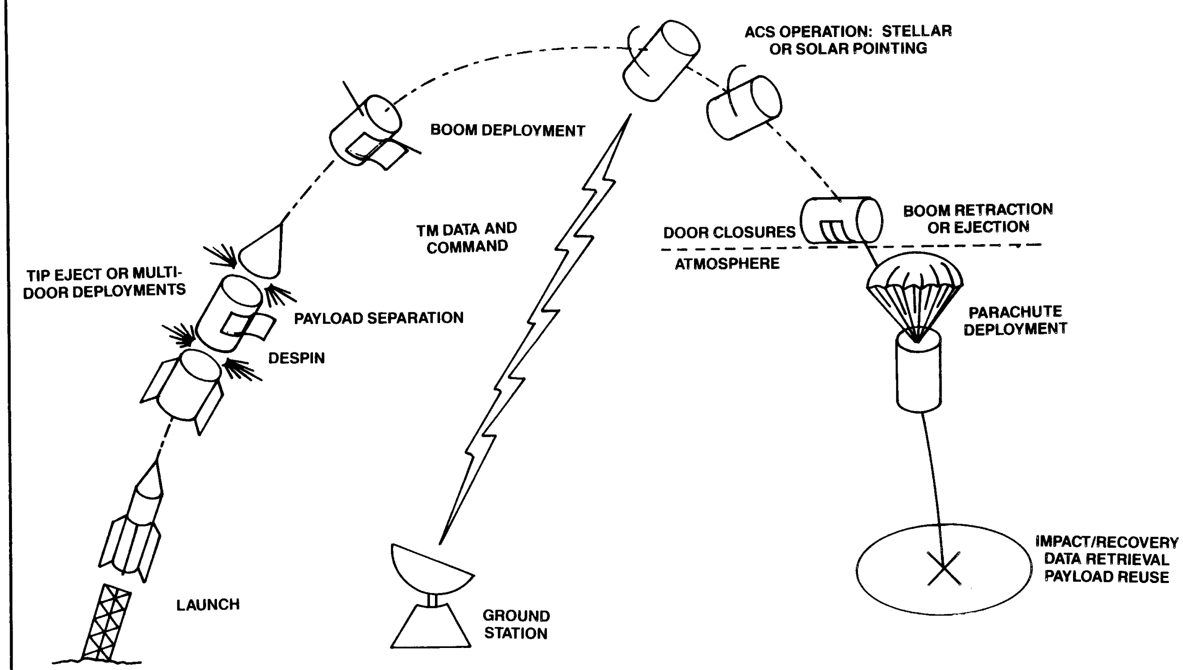


FIGURE 13. TYPICAL SOUNDING ROCKET MISSION PROFILE

D. SAFETY ASSESSMENT

1. Policies and Procedures

a. Range Safety Responsibility - The overall responsibility for safety at the GSFC/WFF is vested in the Director, GSFC. In turn, this overall responsibility is delegated to the Director of the Suborbital Projects and Operations Directorate (SPOD) at the WFF. Within SPOD, the Safety and Quality Assurance Engineering Branch is charged with implementing range safety.[18]

(1) The Head, Safety and Quality Assurance Engineering Branch is responsible for:

(a) Program safety management for WFF programs and launch range activities conducted from Wallops Island.

(b) Reviewing and establishing procedures that assure each project or launch is performed in accordance with established safety policies and criteria.

(c) Approval of any deviation from the requirements set forth in the safety plans.

(d) Assuring that a Ground Safety Plan and a Flight Safety Plan are prepared by the Ground and Flight Safety Section prior to any launch operation. The Ground Safety Plan covers operating variables involving the storage and handling of explosives and propellants, vehicle assembly and pad preparations where other than normal procedures are used. The Flight Safety Plan covers the quantitative and qualitative aspects of the proposed vehicle flight.[19]

(2) The Head, Launch Vehicles Branch, is responsible for:

(a) Exercising control over the operation of the Branch to assure maximum safety and to minimize the taking of unnecessary risks during the preparation of vehicles for launching, and to resolve any conflict between safety criteria and operational exigencies. He appoints a Pad Supervisor who is responsible for coordinating and implementing safety procedures for each operation, and who is responsible for all safety matters within the launch areas.

(b) Referring all unapproved program procedures or activities requiring safety review to the Ground and Flight Safety Section.

(c) Assuring that all power systems and User supplied equipment is inspected before use.

(d) Assuring proper storage and use of all radioactive sources and maintaining records and other documentation.

(e) Providing written authorization for handling and transporting liquid propellants, allowing personnel to take spark-producing devices into explosives handling areas, and for doing repair work on magazines containing explosives or other hazardous materials.

(f) Maintaining solid propellant storage magazines and shipping, receiving and transporting ordnance at WFF.

(g) Maintaining facilities for, and performing, ordnance preinstallation testing.

(3) The Head, Ground and Flight Safety Section, is responsible for:

(a) Establishing ground and flight safety plans which provide the specific safety criteria and procedures to be observed for each launch vehicle and payload.

(b) Providing an engineering evaluation of all vehicles and payloads to assure they meet the ground and flight safety policies, and to categorize ordnance devices.

(c) Developing Safety Analysis Reports for the approval of the Director of Suborbital Projects and Operations for systems which exceed established risk criteria.

(d) Acting as Range Safety Officer for all flights being launched from WFF and any special mobile expeditions as required.[19]

(4) The Test Director is responsible for:

(a) Exercising operational control and coordination of all countdown operations.

(b) Controlling activities in the immediate vicinity of the launch area to prevent unauthorized vehicular and pedestrian traffic, and calling a hold in the countdown when, in the opinion of the Pad Supervisor, such action is necessary in the interest of safety.

(c) Ensuring that the Pad Supervisor is present in the launch area before any operation commences that will create a hazardous condition, or before any such operation that has been interrupted is resumed.

(d) Assuring that all flight safety conditions are in accordance with the Flight Safety Plan prior to launch; i.e., launcher settings, wind limitations, support aircraft, predicted flight course and range clearance areas.

b. Flight Termination System Requirements - A command/destruct capability, which meets Range Safety requirements, is required on vehicles with guidance systems that provide the capability to violate the flight safety limits. GSFC/WFF flight safety policy requires a flight termination system in every stage of a launch vehicle unless it is shown that the flight is inherently safe, which is determined by probability estimates based on known system errors and the following set of qualifying conditions:

(1) The launch vehicle does not contain a control or guidance system and is incapable of assuming any trim angle that produces sufficient lift for the vehicle to violate the planned impact area.

(2) The launch vehicle control system does not have sufficient turning capability to violate the planned impact area.

(3) The acceleration at lift-off must be greater than 3.5 g's and/or there must be a high degree of confidence that the vehicle can be wind-corrected accurately.

(4) For new or modified vehicles, the proposed launch elevation angle does notexceed 80^{0}, and the proposed azimuth is such that the geographical advantages of impact areas are recognized. If the vehicle

reliability has been established, the 80^0 launch elevation angle limit may be exceeded, provided that the probability of failure does not violate flight safety limits and the impact criteria are not violated.

If a launch vehicle cannot meet the above set of conditions, a flight termination system must be employed. The WFF requirement for the flight termination systems is for a reliability of 0.999 at the 95% confidence level. FTS's flown at the WFF are subjected to rigid design review, test and quality assurance standards.

c. Safety Waivers - Range Users must submit requests for any waivers from the prescribed procedures before arriving at the GSFC/WFF. Waiver approval authority is the Director of Suborbital Projects and Operations.

2. Safety Organization - The Safety and Quality Assurance Engineering Branch of the Engineering Division plans, develops and provides functional management of Wallops Flight Facility policies and procedures for program safety. Although the Engineering Division is in the chain of command between the Branch and the Director of Suborbital Projects and Operations, the Safety and Quality Assurance Engineering Branch has direct access to the Director for program safety. This Branch is responsible for initiation of development of new methods, techniques, procedures and/or systems to reduce hazards and improve operating techniques. The WFF RSO works for this organization and is responsible for:

- Assuring that launch safety criteria are met
- Controlling and operating the real time flight termination system
- Establishing requirements of real time data and display system
- Acting as advisor for international programs and training

In addition, the Ground and Flight Safety Section of this Branch is responsible for determining flight safety limits, defining launch limitations and performing risk assessment analyses. See **Figure 14**$_3$ for a block diagram of the WFF Safety organization.

3. Safety Personnel Training - The WFF has established a formal and comprehensive Range Safety Officer training program. Training of RSO's is the responsibility of the WFF Safety and Quality Assurance Branch. Training of other safety personnel who support the RSO during pre-launch preparations, countdown and vehicle flight is also conducted. The following information is provided to outline the steps and procedures involved with training these personnel at the WFF. The training procedures for Range Safety Officers are presented first:

a. Background Requirements - The desired background requirements for a potential Range Safety Officer are:

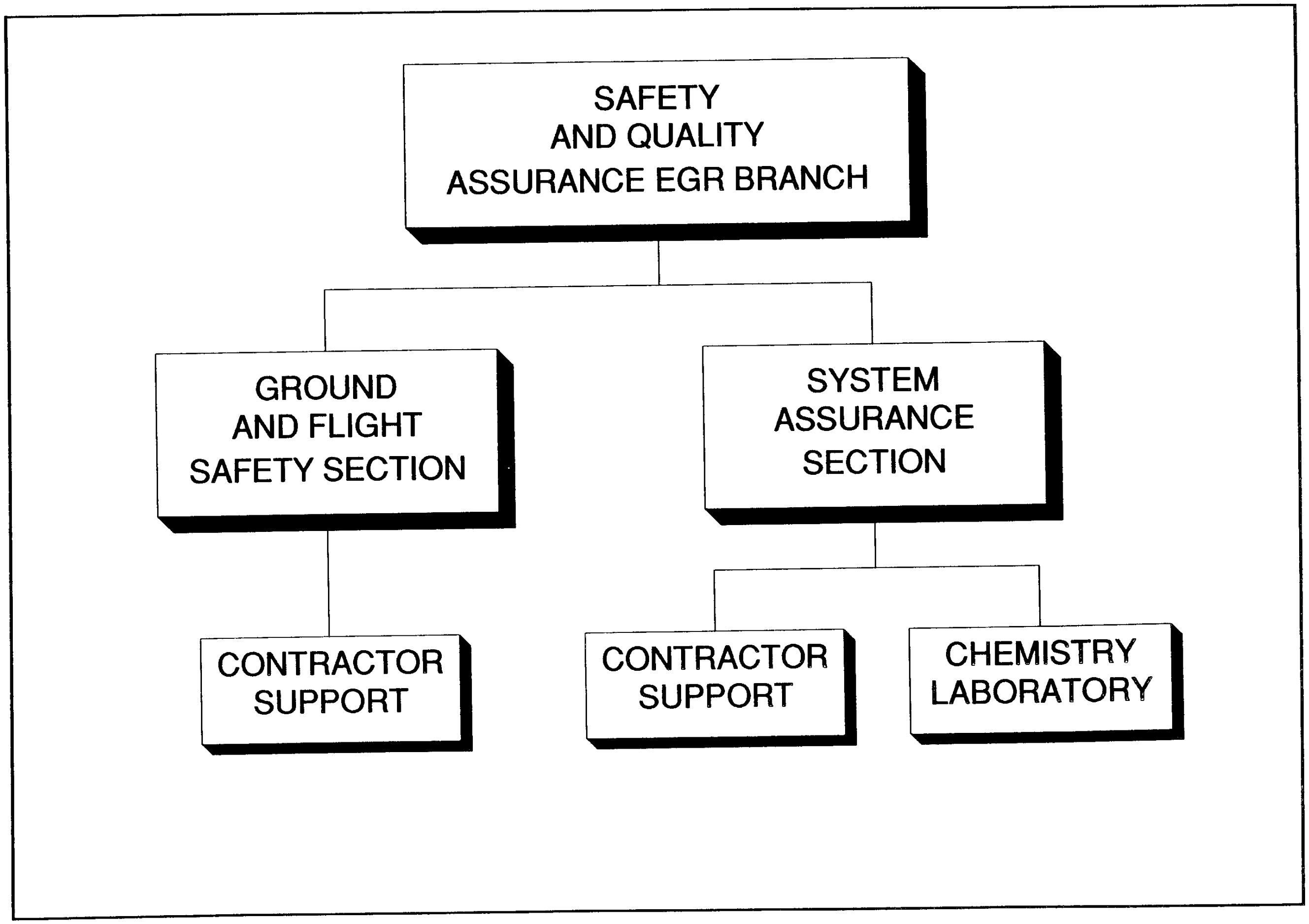


FIGURE 14. WALLOPS FLIGHT FACILITY SAFETY ORGANIZATION

(1) Grade - Must be a U.S. Government employed civilian, GS-09 or above. The grade level required varies, dependent on the complexity of the launch operation. Currently only GS-12 and above civilians are selected to serve as RSO's for orbital missions.

(2) Education - Should have a Bachelor's degree, preferably a master's, in some field of engineering or possess equivalent technical experience. The candidate should understand the application of typical range instrumentation systems, and the behavior of ballistic and aerodynamic vehicles in flight under external forces.

(3) Experience - Should have a background in missile, space or aircraft operations requiring real-time decision making.

b. Training Plans/Certification - Training programs have been developed to assure that candidate RSO's are properly trained and to serve as a documented record of the trainee's progress and performance. An outline of the WFF RSO training program is shown in the following paragraphs:

(1) Wallops Philosophy - The trainee is expected to review and understand the "Range Safety Policies and Procedures" document, probabilistic theory, land, ship and aircraft criteria, casualty expectation criteria, overflight issues and political ramifications involved in mission operations.

(2) Impacts - The trainee must understand the nature of impacting spent stages and debris from a destructed vehicle as it relates to clearing hazardous areas, providing surveillance, defining buffer zones, dispersion characteristics, probability and impact calculations for land, ship and aircraft and casualty expectation calculations.

(3) Overflights - The trainee is expected to become well versed in the area of overflight hazards and risks. This includes the understanding of the principles of land impact probability calculations, casualty expectation calculations, defining acceptable launch corridors and vehicle flight limits such as azimuth/elevation and Instantaneous Impact Prediction (IIP).

(4) Guidance Systems - The trainee is instructed on the types of guidance systems used on the vehicles flown from the WFF. These include the ballistic missiles which have no active guidance system, programmed guidance and seeker guidance.

(5) Flight Safety Limits - The trainee must understand the safety limits as they relate to azimuth and elevation considerations. Azimuth issues such as nominal azimuth to land mass, data source "error", Coriolis effect, turning rates (vehicles with guidance and destruct systems), dispersion (vehicles without a destruct system) and buffer zones. Elevation issues include the pitch program, stage impacts, maximum range considerations and stage burnout considerations.

(6) Hazard Areas - The trainee is expected to understand the definitions of hazard areas used at the WFF, the clearance procedures for the defined hazard areas, the components that make up the hazard areas such as the flight control corridors, data source "error", turn rates

versus reaction time, debris drag impact and buffer zones.

(7) Missile Exercises - The trainee is instructed in the use of missile hazard areas, vehicle destruct lines, aircraft vectoring and missile fire envelopes.

(8) Computer programs - The trainee must understand the various Range Safety computer programs use at the WFF. These include the Nemar 6-D (nominal trajectory, turn rates and drag impacts), Oblate (latitude, longitude, azimuth and range), Time Track ("vacuum" impacts), Map (IIP map and destruct lines), IIP (real-time), SENS-5D (trajectory, wind weighting), ship and aircraft impact probability, casualty expectation and statistical dispersion.

(9) Flight Safety - The trainee is expected to calculate flight safety limits for a given vehicle, have a thorough knowledge and understanding of the use of the real-time IIP information and must understand the issues involved with orbital predictions as they relate to a particular vehicle.

(10) Weather - The trainee must understand the weather constraints and issues involved as they relate to safety. This includes wind considerations (surface and ballistic), visibility (ceiling for skyscreens and visual for aircraft) and temperature considerations.

(11) Flight Safety Plan - The trainee must become familiar with the Flight Safety Plan. After satisfactory completion of the above steps 1-10, he will be expected to write a Flight Safety Plan for a specific mission. This plan includes information concerning the nominal trajectory, impacts and dispersions, hazard areas, flight safety limits, operational safety procedures, clearance and surveillance, weather limitations and Command System requirements (if applicable).

(12) Data Sources and Displays - The trainee must understand and be able to interpret data sources and displays. He will become familiar with radar data (present position, flight azimuth and elevation), radar via real-time computer (velocity, IIP and digital displays), telemetry (pitch program, longitudinal acceleration and command channel), skyscreens (location, purpose and reporting procedures) and camera requirements.

(13) Command System - The trainee is instructed on the use of the Command/Destruct System employed at the WFF. This includes a description of the FRW-2 transmitter system, understanding why it is required on guided vehicles, destruct criteria, FRW-2 status monitoring, power versus range considerations and over the horizon capabilities.

(14) Range Safety Display System - The trainee will be instructed on the setup and use of the display system used at the WFF. This will include information concerning tracking data, destruct lines, IIP plots, wind weighting considerations and simulation techniques and capabilities.

(15) Control Center Operations - The trainee will be instructed on the use of the operations control area. Supporting personnel and their roles in the safety process will be defined. This includes communications,

surveillance, skyscreen, etc..

(16) Failure Modes - The trainee must understand the various failure modes that can come into play during the flight of a vehicle. These can be categorized as: catastrophic, pitch over shoulder, pitch program failure, control system failure (yaw), rocket motor failure, FRW-2 command system (backup system and alternate site), radar (loss of track and side lobe), computer failures, display system failures, communication system failures and power failures. The trainee must be able to understand the repercussions of any of these failures and act accordingly.

(17) Pre-Mission Briefing - The trainee is required to present a pre-mission briefing to safety and operations personnel prior to conducting a specific mission.

(18) Range Safety Officer Simulations - The trainee must be able to complete, successfully, a variety of simulated runs of malfunctioning vehicles under different conditions and failure modes.

This includes off-nominal trajectories, ground and vehicle instrumentation system failures, Range Safety Display System failures, etc..

(19) Certification - The WFF safety office does not certify, formally, their Range Safety Officers. However, upon completion of the RSO training program, the duties of RSO are added to the individual's position description which serves as a permanent record. The WFF safety office provides training and formal certification for internationals. They are certified, formally, by the Director, Suborbital Projects and Operations Directorate, by letter.

c. Range Safety Officer Checkout - Under the supervision of an experienced RSO, the newly qualified RSO must perform in a manner consistent with Range Safety policies and procedures. He will be evaluated and a determination made as to whether or not additional training is required.

d. Recurring Training - As required, proficiency or recurring training is provided to the Range Safety Officer.

e. Training Timetable - The amount of time required to train candidate RSO's varies, depending on the individual's capabilities and the available launch schedule.

However, the typical time schedule for RSO training at the WFF is approximately one year from the time the trainee enters the program until he is qualified to man the RSO console.

4. Range Safety Systems and Support Personnel[20] - The Range Safety System (RSS), located in the Range Control Center (RCC), provides the RSO with the capability for monitoring launches and other special tests. **Figure 15**[10] shows a layout of the RCC. Supporting elements of the RSS such as tracking radars, telemetry instruments, the command transmitters and optical equipment are located at sites on the Wallops Mainland, at Wallops Island and downrange at Bermuda. The RSS and supporting personnel consist of the following:

a. RSO Console - This is the focal point for Range Safety functions during launch operations. It is manned by the Senior RSO and primary RSO. The RSO console provides the following: 1) - launch vehicle present position and predicted impact point data displays for comparison with flight termination criteria, 2) - video monitors displaying various television camera views of the vehicle in flight, as well as launch area conditions, 3) - range "Holdfire" control and indicators, 4) -control units to initiate flight termination action, 5) - voice communications with other Range Safety personnel, WFF controllers, launch agency controllers and other stations as required and 6) - the ability to compute, in real-time, limits of acceptability which follow allowable Range Safety criteria.

b. Range Safety Display System (RSDS)/RSO - The RSDS is located in the RCC and consists of dual consoles, each with four monitors whose displays are real-time selectable by the SRSO or RSO. These are redundant systems as are all elements of the Range Safety system. The RSDS allows continuous monitoring of vehicle performance by the SRSO and RSO to determine whether vehicle behavior is nominal. Data available to the SRSO/RSO include vehicle Instantaneous Impact Point (IIP), Present Position (PP), destruct lines and background maps. Alphanumeric data in the left and right margins of the displays provide information concerning vehicle tracking sources, vehicle altitude, velocity, heading, etc..

Additionally, multiple sensor (radar) tracking data is input from the Range Safety computer to the RSDS. This allows the RSO to have two independent tracking sources to compare. Though there is a multiplicity of data and tracking information available to the RSO, it is important to recognize that the RSO must exercise his judgement in making a decision to terminate vehicle flight.

(1) Displays - Tracking information is displayed on the RSDS monitors. Each system (A and B) drives four of the eight monitors on the RSO console to preclude loss of all display capability from any single failure. Each monitor is independently controlled by an individual function keyboard which selects formats for display.

(2) RSO - He is responsible for monitoring displays during real-time flight to evaluate tracking and performance data. The RSO works in conjunction with other supporting personnel (i.e., Senior RSO, Radar Coordinator, Test Director, Skyscreen, etc.) during launch operations in order to provide the greatest amount of coordination possible.

(3) SRSO - He assists the RSO with problems encountered during the prelaunch countdown and, when time permits, provides information and concurrence with the decision to terminate vehicle flight. The SRSO has the authority to "overrule" any decision the RSO may have made. The SRSO monitors displays and communications with safety personnel and other support organizations.

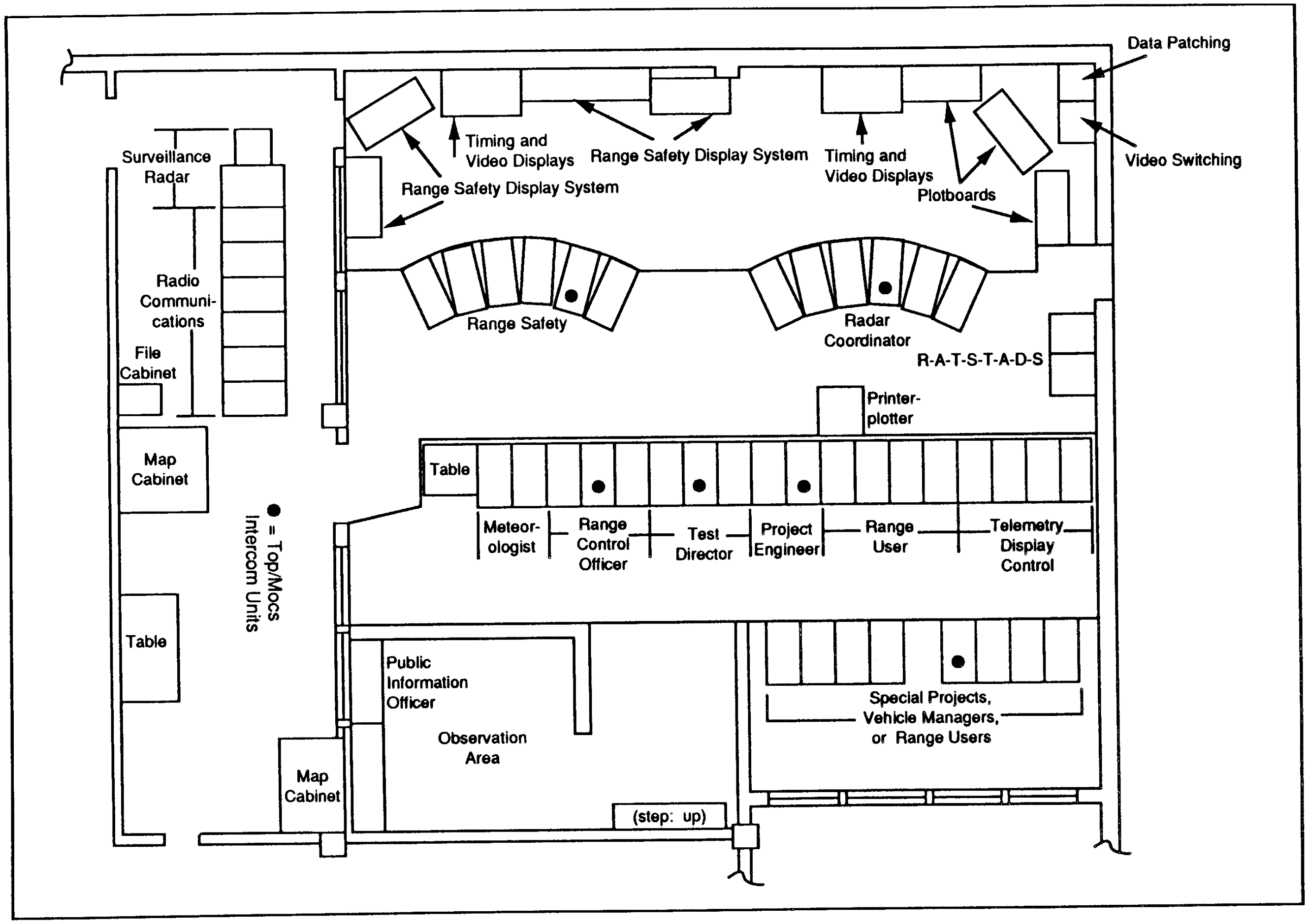


FIGURE 15. WFF RANGE CONTROL CENTER

c. Command/Destruct System - The transmitter site maintains two independent command systems which are electronically linked to the Range Safety Officer's console during an operation, and whose antennas track the vehicle during flight. (Specifically, they are provided pointing data from the tracking radars). Two monitor channels are used to verify that the transmitters are locked onto the command receivers in the vehicle. The Range Safety Officer can send a destruct command using a two step procedure:

(1) ARM DESTRUCT SYSTEM

(2) SEND DESTRUCT COMMAND

In case of an electronic failure between the Control Center and the transmitter site, the RSO can instruct transmitter site personnel to send the destruct command.

Flight safety limits are established for each flight. Vehicles that violate the flight safety limits create an immediate safety hazard and must be destroyed. During flight, the Range Safety Officer must evaluate whether the vehicle is violating the flight safety limits. He does this by observing and evaluating his data sources.

Normally, the RSO will not destroy the vehicle on the basis of one data source; he will try to verify a failure from several different data sources. This is one of the reasons why there are multiple, and sometimes redundant, data sources. Additionally, this provides backup data sources in the event of a failure. Also, the RSO must have sufficient time to evaluate data when a potential exists for a destruct situation.

The RSO must be aware of the effective range of the command/destruct system. He must assure that the vehicle is within command range at all times. For some missions, this requires having another command system downrange. Bermuda is sometimes used for this purpose. Through a telemetry channel, the RSO can monitor commands being sent and these commands can be recorded for a permanent record.

d. Range Safety Telemetry Display System - This system provides real-time telemetry which is used to monitor vehicle performance. Such events as stage ignition can be verified by telemetry data. A specific example being that a vehicle's pitch program can be monitored to verify that the guidance commands are being generated. Pitch, roll and yaw data is displayed in order to assess vehicle attitude. The command/destruct monitor channels provide the RSO with information on the transmitter carrier, and whether or not the system has been armed. Besides displaying vehicle data, telemetry data can be used as a back-up source to confirm a vehicle failure. The telemetry data can be displayed in the Control Center or can be communicated by intercom to the RSO from Range Safety personnel located at the telemetry site.

The telemetered data is not used as an input to the Range Safety computers for computation of the vehicle's IIP.

e. Radar Tracking Systems - Radar tracking systems are the primary data sources used by Range Safety with real-time vehicle radar tracking data being routed to the Range Safety computers for processing. Azimuth, elevation and range data are fed into the computers for calculation of IIP data. This information, along with velocity data, is transferred to the RCC and formatted in the RSDS computers for display to the RSO.

Range support personnel perform prelaunch testing of the radar network and verify that all critical support requirements are met. During real-time operations, the Radar Coordinator controls the radar systems and, in the event of a radar malfunction or tracking problem, selects alternate sources to assure that information is constantly available to the RSO.

f. Optical Systems - Multiple cameras provide real-time video of the launch vehicle for use by the RSO. Azimuth and elevation angle data is not provided to Range Safety for use in computing Instantaneous Impact Point information.

g. Skyscreens - Skyscreens are visual data sources used to observe vehicle trajectories during the early stages of flight (approximately 0-15 seconds). Skyscreen personnel, who are in radio contact with the RSO, detect vehicles violating the flight safety limits and report this information to the Range Safety Officer. The skyscreen locations are approximately 1 to 2 miles from the pad.

h. Surveillance Control - The central control station for surveillance is located in the RCC and is operated by Range Safety personnel. The surveillance control representative monitors sea (ship and boat) traffic in the predetermined hazard area. If hazards exceed an acceptable level ($1x10^{-5}$), the RSO waits until surface vessels move to a safe position. If hazards cannot be reduced to an acceptable level, the RSO may call a hold to the launch countdown until hazards are clear. Voice communications are provided to supporting surveillance aircraft, radar sites and air controllers.

Surveillance radars are used to control impact risk for launches from WFF. Radar systems such as a Mariners Pathfinder, ASR-7 and APS-128E or APS 80, are employed to determine the location of ships and aircraft. These radar systems survey impact areas out to approximately 100 nautical miles. Using the ship data reports, the RSO can determine if ship impact criteria are satisfied. If the criteria are satisfied, the launch may proceed.[21]

i. Emergency Response - The Chief, Health, Safety and Security Office, works for Industrial Safety and is responsible for directing Crash, Fire and Rescue Company efforts and mutual aid support, as required, in the event of an explosion, fire or errant vehicle, both on and off WFF property. In addition, he insures that Crash, Fire and Rescue Company personnel respond to directives issued by the RSO and/or Test Director during launch operations or emergencies.[18]

The Crash, Fire and Rescue Company is an organization hired to perform these functions should a malfunction occur which results in unplanned impact, explosions or fire. A recovery team normally consists of these people, augmented by personnel from Launch Operations, Security and Safety.

5. Safety Restrictions - Safety restrictions are established by Range Safety personnel for the launch vehicles launched from the WFF. In general, the vehicles must be launched in an easterly or southeasterly direction and on an azimuth that provides protection for land masses and populated areas from debris. All flights are planned in accordance with impact agreements and conducted so that the planned impact or reentry of any part of the launch vehicle over any land mass, sea or airspace does not produce a casualty expectancy greater than 10^{-7} and an impact probability on private or public property, which might cause damage, greater than 10^{-3}, unless a Safety Analysis Report is prepared and approved, or it can be proven that:

- The reentering vehicle will be completely consumed by aerodynamic heating, or
- The momentum of solid pieces of the reentering vehicles (balloons, parachutes, etc.) will be low enough to preclude injury or damage, or
- Formal Government or private agreements allow the use of the land mass for impact or reentry.

No vehicle may overfly a populated area in violation of previous Governmental or private agreements unless the vehicle is in orbit or the probability of an overflight failure does not violate impact criteria, or unless approved in a Safety Analysis Report.[18]

a. Flight Azimuths - For Scout vehicles, launch azimuths between 109^0 and 126^0 are restricted due to the fact that the second stage has an unacceptably high probability (greater than $1.0x10^{-3}$) of impacting on the Island of Bermuda. However, flights on these azimuths are not always ruled out (a Safety Analysis Report might be approved).[3] Refer again to **Figure 6** for a graphical representation of the restricted flight azimuths. Sounding rockets are restricted to azimuths normally ranging from 90^0 to 165^0.

b. Launch Area - Other restrictions established by Range Safety include:

(1) Danger Areas - That area, including impact areas, abort areas or malfunction debris or hazard areas, in which the hazards from launch vehicle stages, debris or toxic materials exceed the established maximum, acceptable risk level.

Procedures for determining the explosive and flight control hazard areas are briefly described below:

- Explosive Hazard Area - The danger area for any given vehicle launched from the Wallops range can be described as a circle around the launch pad. It is common practice to use the following formula to determine this distance:

$$\text{Distance (D)} = 80\ (\text{Total TNT equivalent weight of propellants})^{1/3}$$

Typical explosive hazard areas range from approximately 390-1250 feet.

- Flight Control Hazard Area - This area is vehicle dependent in that it is directly related to vehicle performance parameters, i.e., acceleration. Fragment data is not used in the determination of this hazard area. Known trajectory data is simulated to build malfunction turn information necessary to define this area. The Flight Control Hazard Areas range from approximately 3000-6000 feet and are oval in shape.

(2) Danger Time - That time period when any electrical operation, arming, explosive installation, launching or other dangerous function is taking place.

(3) Caution Time - That time period when any explosive devices are in the launch area. When a caution time exists, nonparticipating

personnel are allowed to enter a launch area only when authorized by the Pad Supervisor. Active-essential and standby-essential personnel continue working during a caution time.

(4) Active-Essential Personnel - Those individuals whose activities contribute directly to the preparation of a launch vehicle or support equipment for a specific operation which is actually under way, and whose presence is mandatory for completion of the operation.

c. Impact/Hazard Areas - Impact Areas are calculated for expended booster stages, payload fairings or any other significant parts that are jettisoned along the planned flight path. Examples of impact areas for items jettisoned from a Scout launch vehicle and a Black Brant X sounding rocket are shown in **Figure 16**[8] and **Figure 17**[17]. These impact areas must be in the ocean. All impacts within the Virginia Capes operating areas (VACAPES) require clearance from Fleet Area Control and Surveillance Facility (FACSFAC) prior to launch. In addition, GSFC/WFF will request Notice to Mariners (NOTMARS) and Notice to Airmen (NOTAMS) to be issued prior to the launch date. All impacts outside VACAPES require clearance with the FAA. GSFC/WFF is responsible for obtaining this clearance, and to do this, Range Users are required to provide the predicted impact related dispersion data for each re-entering body. It has been common practice to apply an acceptable-risk, ship-hit criterion of one in one hundred thousand (i.e., $1x10^{-5}$) to ships and boats.

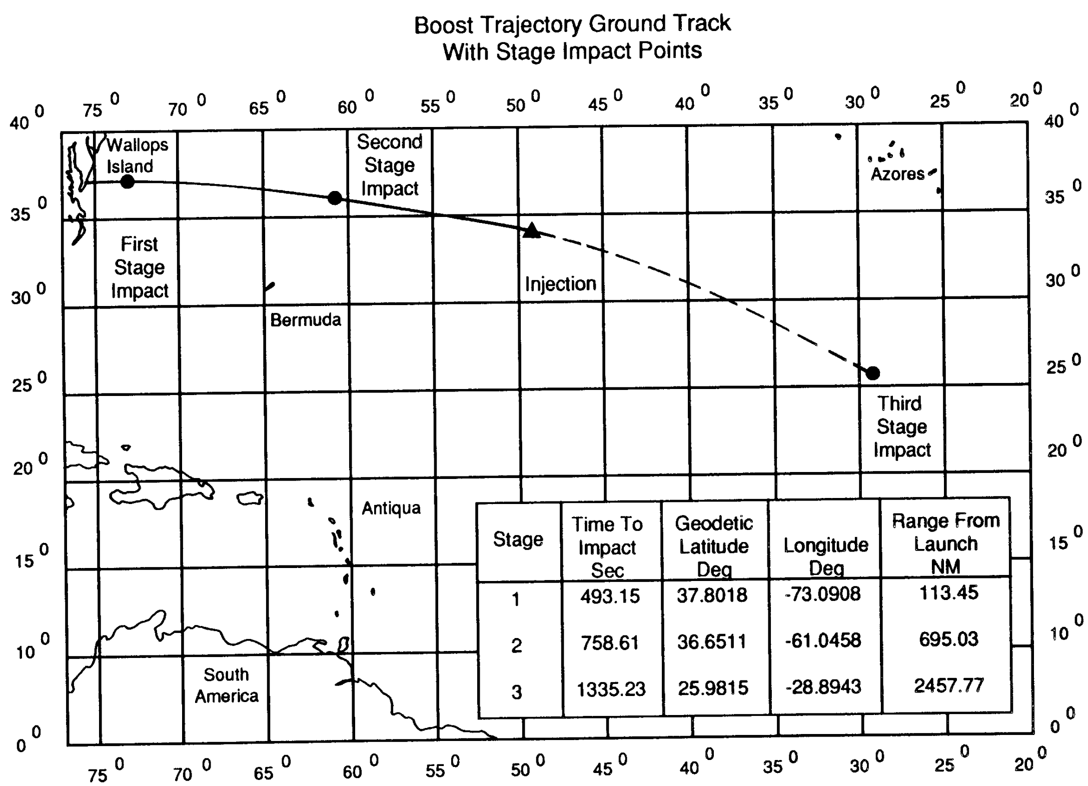
Because aircraft are more vulnerable than ships, an impact probability of one in ten million (i.e., $1x10^{-7}$) is used. There has never been a confirmed report of a jettisoned vehicle part striking an aircraft or ship. The probability of an object impacting in a land area must be less than, or equal to, $1x10^{-3}$.

(1) General - The operational hazard area is that area which must be kept clear of ships and aircraft. For unguided vehicles (most sounding rockets), the size of the hazard area is such that the probability of hitting a ship or aircraft just outside of the area is less than the accepted probability ($1.0x10^{-5}$). For guided vehicles with a destruct system, the destruct limits are calculated such that all impacts are contained within the hazard area.

Impact clearance must be obtained for the operational hazard area. Normally, additional area is obtained to provide for shifts in hazard area location and for use as a buffer. Clearance requests are normally based on the size of the aircraft hazard area since this area is normally larger than the ship hazard area.

For unguided systems, the operational hazard area is basically a function of two variables:

- Size of the impacting vehicle
- Dispersion



Stage	Time To Impact Sec	Geodetic Latitude Deg	Longitude Deg	Range From Launch NM
1	493.15	37.8018	-73.0908	113.45
2	758.61	36.6511	-61.0458	695.03
3	1335.23	25.9815	-28.8943	2457.77

FIGURE 16. SCOUT IMPACT DATA FOR JETTISONED ITEMS

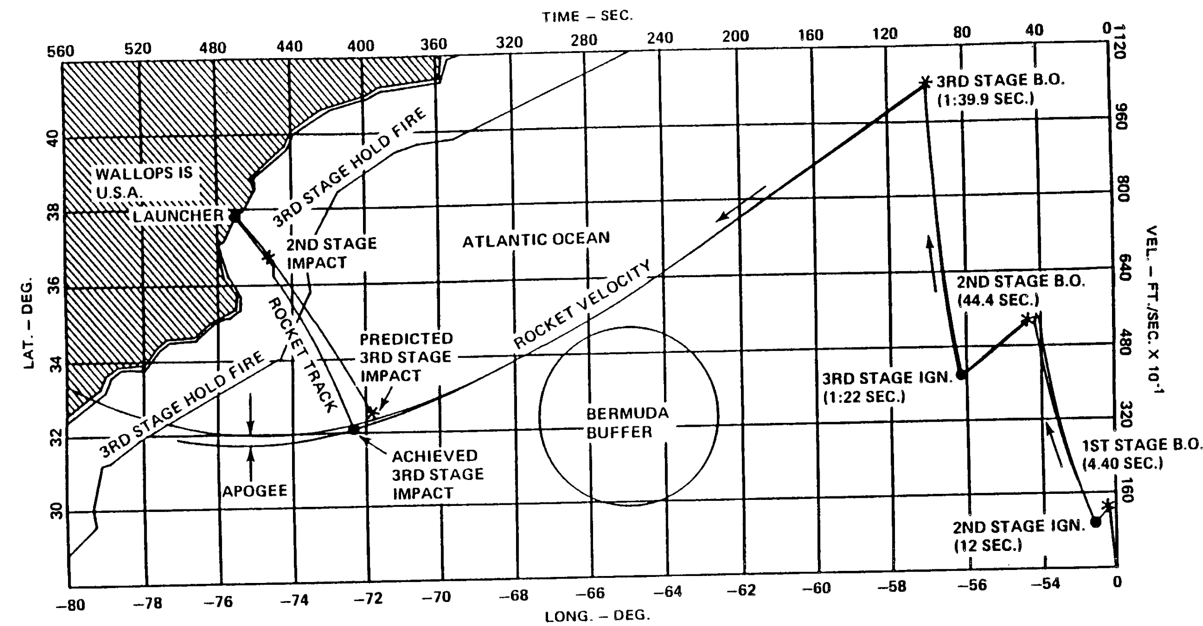


FIGURE 17. BLACK BRANT X IMPACT DATA FOR JETTISONED ITEMS

For guided systems, the hazard area is a summation of a number of components that result in a maximum deviation from the nominal flight path:

(a) Flight Control Corridor - Preprogrammed guidance systems cause the vehicle to fly a predetermined trajectory within a certain variance, usually identified by a 1-sigma variance.

(b) Data Source "Error" - The accuracy in which the Range Safety Officer knows the location of the vehicle (radar/display accuracy).

(c) Turn Rates/Reaction Time - It takes the RSO a certain finite amount of time (usually 3-5 seconds) to detect a malfunctioning vehicle, determine that the flight safety limits are being exceeded and to initiate the destruct action. Turn rates are calculated to determine the maximum distance that an errant vehicle can traverse during this reaction time.

(d) Debris Drag Impact - This is the distance that the vehicle debris traverses after destruct has occurred. It is a function of four parameters: altitude, velocity, flight path angle and the drag coefficient of the debris particle with the furthest impact range. (Heavy particles with low drag go the furthest after destruct.)

(e) Buffer - A buffer is a "cushion" factor added on to a hazard area for such purposes as to compensate for inaccuracies in reporting the location of ship and air contacts and any uncertainties in the hazard area calculations.

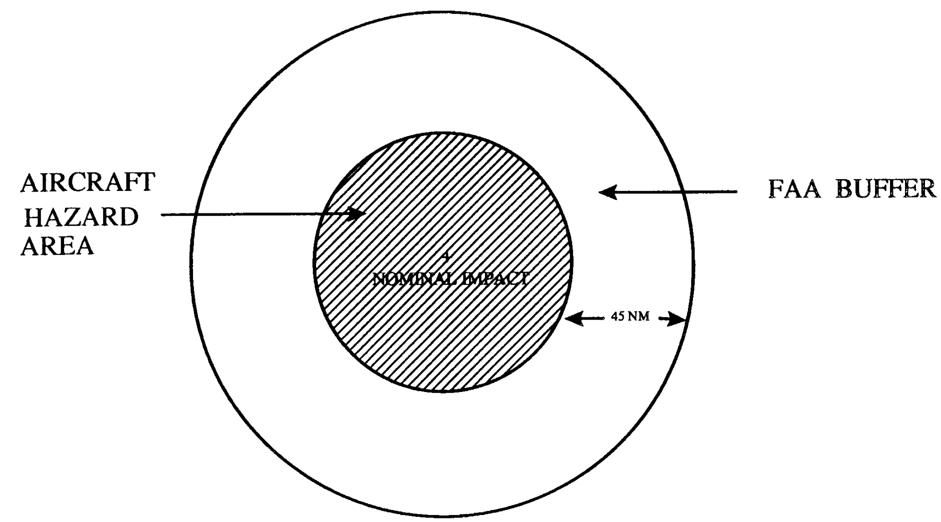
(2) Aircraft Hazard Area - Missile operations inherently produce a hazard to aircraft in the vicinity of the vehicle impact area or spent stage impact areas. WFF's policy requires that an aircraft hazard area be established to protect aircraft and passengers against the risk of a vehicle/aircraft impact. A typical aircraft hazard area is shown in **Figure 18**$_{22}$.

WFF has an existing agreement with the FAA that specifies responsibilities and procedures for protecting aircraft during launch operations. This documentassigns WFF the responsibility for assessing the hazard to aircraft and for determining the size of the hazard area. The FAA routinely adds a 45 nm buffer to the Wallops hazard area.

Range Safety computes the aircraft hazard area based on the casualty expectancy criteria specified in GHB 1771.1 ($1x10^{-7}$). Use of this criteria can result in large hazard areas for vehicles with large dispersions.

(3) Launch Hazard Area - A launch hazard area for the Scout vehicle is defined as a circle with a 0.9 nautical mile radius centered on the launch pad. For other launch vehicles, this area is the "Inhabited Building Distance" (defined in AFR 127-100) as determined by the amount of vehicle propellant.

(4) Sounding Rocket Dispersion - Dispersion of the impact location of a rocket is the statistical deviation of the actual impact point from the nominal impact point due to uncertainties in modeling parameters (e.g., wind). It is used to calculate the probability of impacting within a given distance of the nominal impact point. This distance is commonly expressed as a sigma value (the square root of the average of the squares of the deviations from the mean).



Note: Aircraft Hazard Area is based on 1.0X10-7 Hit Probability to Aircraft

FIGURE 18. AIRCRAFT HAZARD AREA

The probabilities of impacting within the indicated sigma values for a circular dispersion are:

1 sigma	0.393
2 sigma	0.865
3 sigma	0.989

There are two commonly used methods of determining dispersion which are used at Wallops and are discussed in the following paragraphs:

• Theoretical Dispersion - The theoretical dispersion is determined by varying each of the parameters that affect impact range or azimuth. Typical parameters that are used to determine dispersion characteristics of multi-stage sounding rockets include: thrust misalignment, wind error, weight error, drag error and elevation error. Each parameter is varied by an amount determined by engineering experience to be approximately the same sigma value as will be used to define the dispersion. Computer runs are then made to calculate the difference in impact points for each parametric variation.

The total dispersion is determined from the individual parameters using the root means square (RSS) method.

$D = (D^2 1 + D^2 2 + ... D^2 i)^{1/2}$

The dispersion for a guided rocket is calculated similarly. In general, a guidance system is pre-programmed to cause the rocket to fly a certain trajectory. The variability of this trajectory depends on how accurately the guidance system can detect deviations from the nominal trajectory and the capability of the control system to adjust the vehicle flight to correct these deviations.

• Flight History Dispersion - The flight history dispersion is determined by comparing the actual impacts to the predicted impacts. This method yields good dispersion numbers if a sufficient number of flights for a similar payload weight and launch parameters are available.

(5) Wind Effects for Sounding Rockets - Wind can significantly affect the flight of rockets. Unguided rockets must be wind-corrected to fly the planned trajectory. Prelaunch winds (initially taken at approximately 3 hours prior to launch) are used to determine the launch azimuth and the launch elevation angle which will result in the vehicle flying the desired trajectory. High or gusty winds (on the order of 30-35 mph or gusts above 45 mph) may make it unsafe to launch a rocket. Even for guided rockets, the winds may get so strong that they saturate the vehicle guidance system. A rocket is normally wind-corrected so that the desired trajectory is achieved and the predicted vehicle impact of the last stage is in the planned area. This may not result in the booster stage impact being in its original planned impact area. Separate booster wind correction and drift calculations must also be made to determine it's impact location and to assure that the predicted booster impact location is in a safe area.

Wallops Range Safety personnel use a 5-degree of freedom computer program named SENSE 5D, which is tailored after the Lewis or Unit Wind method, to aid in determining the proper launcher settings to be used for any given sounding rocket mission. This wind weighting procedure is used prelaunch as a predictor.

Parameters such as:

• Tower Tilt - number of nautical miles per degree of elevation,

• Ballistic Wind - sum of the weighted winds for each altitude layer

• Unit Wind - number of nautical miles per feet per second of the ballistic wind

• f curve - the sensitivity of the launch vehicle to wind versus altitude are computed by the SENSE 5D computer program and are used in determining the adjustments to the launch flight azimuth and elevation angles for sounding rocket launches.

During actual launch operations, the SENSE 5D program uses actual wind data taken from balloon tracking information and used to fine tune the launcher settings to obtain the desired trajectory and stage impact locations. Radar reflective balloons are released at predetermined times prior to the scheduled launch time. Also, there is an occasional use of radiosonde equipped balloons for this purpose. These balloons are tracked by radars located on the Wallops range. This tracking information is received/processed and used in the SENSE 5D computer program, which outputs the appropriate launcher settings necessary to compensate for the "actual" winds and achieve the desired trajectory and stage impact locations. These balloons are released and tracked to the burnout altitude of the final stage or a maximum of approximately 100,000 feet in altitude. Low altitude (< 300 feet) wind data is obtained from anemometers mounted on towers located at various places on the Wallops range. As launch time approaches, balloons are only tracked to 5000 feet with the last one released at approximately 15-20 minutes prior to launch. With an ascent rate of approximately one thousand feet per minute, this allows ample time for processing of radar tracking data and subsequent determination of appropriate launch parameters as near to launch conditions as practical.

An example of a wind weighting calculation for a typical sounding rocket second stage is shown below:

To compute the adjustments to vehicle flight azimuth and elevation angle required to compensate for wind, it is first necessary to select the altitude levels that are representative of the mission. The Black Brant X vehicle is used for this example.[35]

The change in vehicle sensitivity (Delta F), see **Figure 19**, to the wind in the appropriate altitude level is multiplied by the N/S and E/W wind profiles (shown in the table below) to obtain the ballistic wind for each altitude level selected. It is important to note that approximately 80% of the wind effects occur during the first stage flight of a sounding rocket.

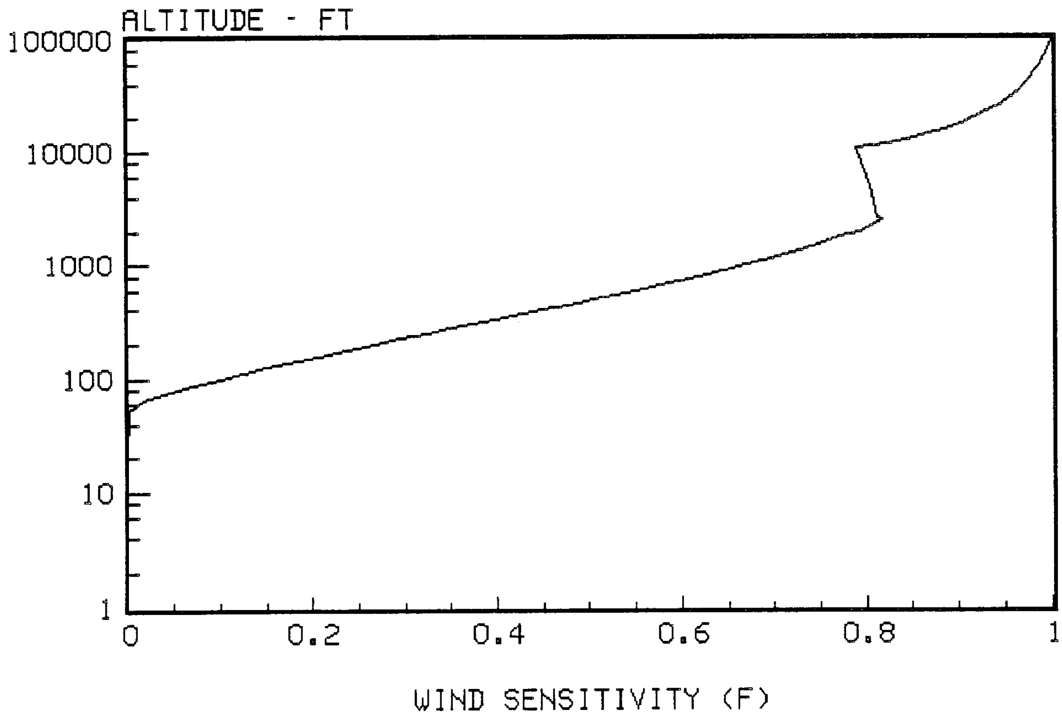


FIGURE 19. VEHICLE ALTITUDE VS WIND SENSITIVITY

Table 6 below shows the altitude levels, vehicle sensitivity (Delta F)/altitude interval, N/S and E/W wind profile and the resultant ballistic winds used for this example.

TABLE 6. WIND WEIGHTING DATA

ALTITUDE (FT)	ΔF VS ALT LAYER	ACTUAL WINDS		BALLISTIC WIND	
		N/S $\dot{X}$ FT/SEC	E/W $\dot{Y}$ FT/SEC	N/S $W\dot{X}$ FT/SEC	E/W $W\dot{X}$ FT/SEC
33 - 100	.100	20	-20	+2.0	-2.0
100-225	.194	21	-25	+4.1	-4.9
225-400	.153	22	-20	+3.4	-3.1
400-800	.171	28	-15	+4.8	-2.6
800-1600	.136	35	-10	+4.8	-1.4
1600-2500	.064	50	-15	+3.2	-1.0
2500-10,914	-.029	-20	-20	+0.6	+0.6
10,914-16,000	.097	-45	45	-4.4	+4.4
16,000-27,500	.063	-50	20	-3.2	+1.3
27,500-45,000	.029	-28	25	-0.8	+0.7
45,000-98,836	.022	-22	15	-0.5	+0.3
Totals	1.000			+14.0	-8.0

The individual ballistic winds are then summed to obtain the total effect of the N/S and E/W wind profiles, i.e. +14 for N/S (from the north) and -8 for E/W (from the west) in this example. The total ballistic wind for the N/S (+14) and E/W (-8) components is then multiplied by the appropriate unit wind factor for crosswind (2.0 N/S) and tailwind (1.96 E/W) obtained from reference 31. This is shown in the following expression:

N/S component = +14 ft/sec X 2.0 nm/ft/sec = +28 nm
E/W component = -8 ft/sec X 1.96 nm/ft/sec = -16 nm
This will have the effect of driving the impact point from the desired location as shown in **Figure 20** below:

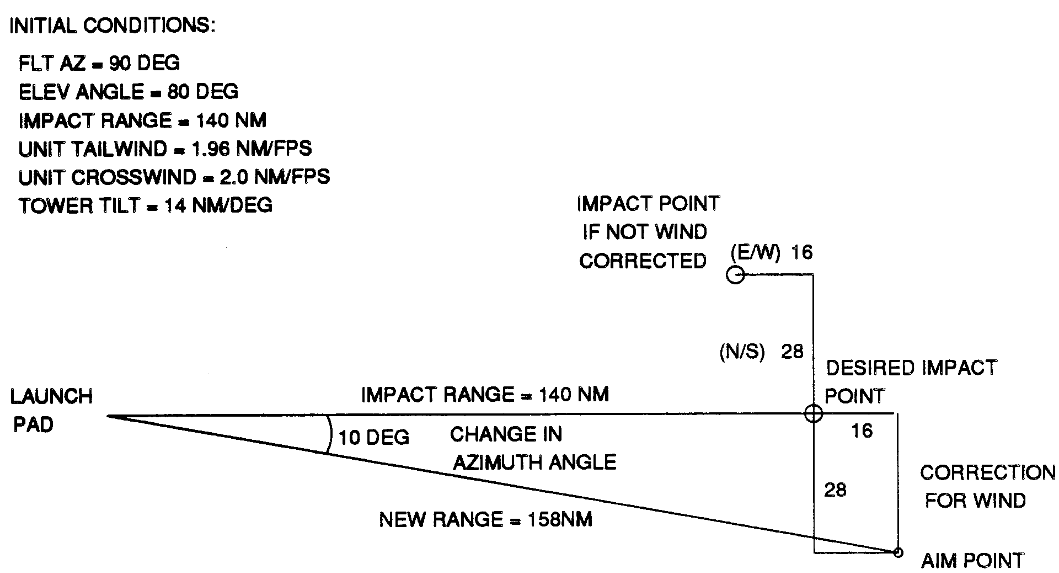


FIGURE 20. SECOND STAGE IMPACT POINT WIND CORRECTION

In order to compensate for the wind effects, the flight azimuth and elevation angles must be adjusted. First a computation must be made to determine the new range component which has resulted from the wind effects. This is found by:

$R^2 = (156 \text{ nm})^2 + (28 \text{ nm})^2$

$R = (24{,}336 + 784)^{1/2} = 25{,}100^{1/2}$

$R = 158 \text{ nm}$

Next it is necessary to compute the change in the flight azimuth. This is done by solving for the angle made between the launch point and the adjusted aim point shown in the above figure. Since the sine of the angle = 28 nm/158 nm = .1772, then the change in the flight azimuth is approximately 10^0. Therefore, $90^0 + 10^0 = 100^0$ which is the adjusted flight azimuth for this example.
To find the new launch elevation angle the following expression is used: El angle = New Range/Tower Tilt = 158 nm/14 nm/deg_{35} = ~11.3^0 The adjusted elevation angle is then, $90^0 + (-11.3^0) = 78.7^0$ Hence, the vehicle must be launched on a flight azimuth of 100^0 (to compensate for wind effects) with an elevation angle of 78.7^0 (to compensate for the increased range) to obtain the desired trajectory and impact point at 140 nm. The adjustments to the flight azimuth and the elevation angle has a direct effect on the first stage nominal impact point. The new impact point must be determined and appropriate action taken by range safety personnel to assure that the impact location is clear of boats, ships and aircraft during sounding rocket launch operations.

d. Impact Limit Lines - The Impact Limit Lines (ILL) define geographical areas to be protected during launch. The Instantaneous Impact Point (IIP) is the point at which a rocket would impact if it stopped thrusting at a given time (assuming a ballistic trajectory to impact). The IIP coincides with the nominal impact point after nominal burnout. In the immediate launch area, the ILL's are selected in order to provide protection for critical and/or expensive facilities and public areas that could be exposed to risks associated with launch operations. The public is normally excluded from sites that are within the ILL and, hence, the public risks are negligible. The IIP prediction capability can be used as a real-time tool by the RSO. The RSO can determine at any time during the flight where the impact would occur if the vehicle flight were terminated at that time. Since this information is based upon the actual position of the vehicle, the dispersion factor is not considered for the destruct limits on the IIP display. If the IIP track is heading towards a land area, the RSO can send the destruct command when the IIP track crosses the destruct line. The IIP track is also used to compute dwell time over a land area (either prelaunch from nominal data or in real-time) by the RSO.

e. Orbit Predict - As an example of Orbital Prediction, the Scout orbital parameters can be predicted once the third stage burnout parameters are known. This prediction technique assumes a nominal fourth stage performance. There is an orbital injection "window" that the vehicle must pass through if it is going to achieve a satisfactory orbit, i.e., a perigee of at least 50 nautical miles. If the flight elevation angle is too high or too low at fourth stage ignition, the vehicle will not achieve orbit. If it does not achieve orbit, the fourth stage plus payload will impact somewhere on the first pass around the earth.
The predicted orbital parameters can be displayed after third stage burnout. If the predicted perigee is less than 50 nautical miles, the payload will not achieve a satisfactory orbit and the vehicle is destructed. An example of the orbital parameters displayed to the RSO are:

- Velocity (at fourth stage burnout)
- Apogee

- Perigee
- Orbit Inclination
- Latitude (fourth stage impact)
- Longitude (fourth stage impact)

f. Destruct Lines - Destruct lines, or flight termination lines, define the flight limits used for terminating vehicle flight. Activation of the FTS by the RSO upon violation of the destruct lines prevents significant debris from penetrating the ILL. Destruct line location is determined by accounting for system delays, data inaccuracies (includes tracking system errors) and debris dispersions. Destruct lines are constructed between the nominal trajectory and the ILL. If the IIP crosses the destruct line and flight termination action is taken, the significant launch vehicle fragments will not impact beyond the ILL. As an example, **Figure 21**$_3$ shows a typical set of sounding rocket destruct lines.

g. Mission Rules - The Mission Rules are documented in the Flight Safety Plan developed for each mission and is coordinated with the operations branch head. Representative mission rules for a vehicle launch are as follows:

(1) Standard Rules

(a) Violation of fixed "destruct lines" will result in termination of vehicle flight.

(b) Violation of immediate launch area present position destruct criteria will result in termination of vehicle flight.

(c) If the vehicle performance is "Obviously Erratic" (out of control) and further flight is likely to increase the hazard, the RSO, based on his judgement, has the authority to terminate flight. This could occur by either interpretation of displayed data or by reacting to verbal calls from the Skyscreen Observer.

(d) If vehicle tracking status becomes "unknown" and the capability to violate an ILL exists, the RSO will make a judgement whether or not to terminate flight. If the vehicle performance has been normal after launch for an extended period of flight (which is not defined) prior to becoming unknown, the RSO may elect to allow the flight to continue. The RSO must evaluate all performance parameters and available data, and determine whether mission rules can be violated or if potential exposure to the public domain necessitates destruction of the vehicle.

(2) Scout Vehicle Unique Mission Rule (an example of a Mission Rule tailored for a specific launch vehicle) - Due to the nature of the Scout vehicle and the launch trajectories that are flown from WFF, it has been determined through analysis that no destruct action will be taken after nominal 3rd stage burnout. If it is determined in real-time that a proper orbit cannot be attained, transmission of the destruct command to the 3rd stage will be made, thus inhibiting 4th stage ignition.

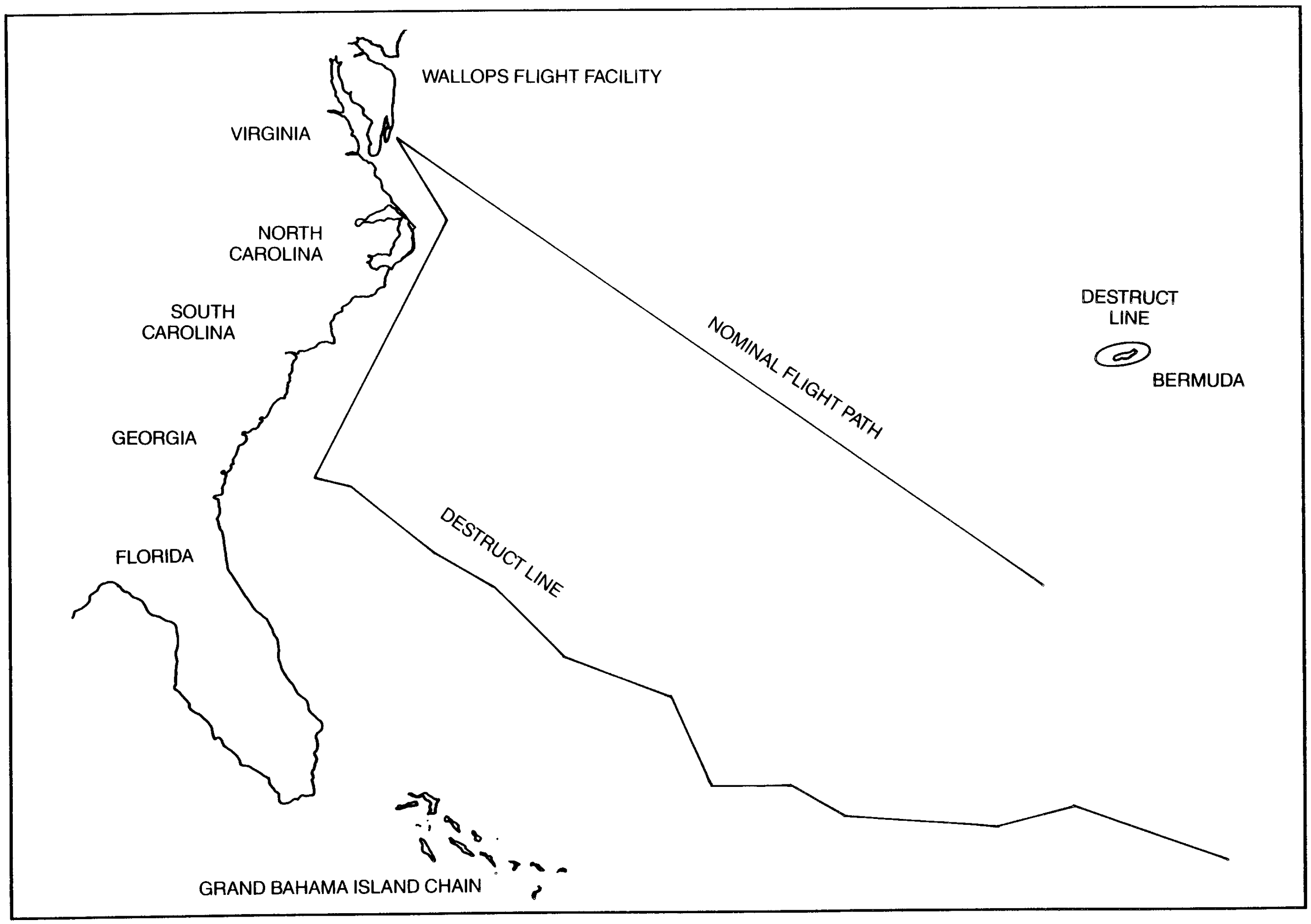


FIGURE 21. TYPICAL SOUNDING ROCKET DESTRUCT LINES

h. Range Safety Priority Items - For each mission, the Range Safety Officer determines the priority items necessary to meet minimum safety requirements. These items are normally documented in the Operations Directive for a particular program, vehicle or mission. There are three levels of priority items:

Priority 1 - Required Operational for launch (Mandatory)
Priority 2 - Highly Desirable but not mandatory for launch
Priority 3 - Holds to the launch countdown will not be called for these items

The priority 1 items for the Scout vehicle are (they vary according to vehicle/mission):

(1) WFF Radar - Vehicle position data from one skin tracking radar through 1st stage separation and vehicle position data from two beacon tracking radars through 3rd stage burnout
(2) WFF Command System - Command/Destruct
(3) WFF Main Base Telemetry - Vehicle telemetry data and spacecraft telemetry data
(4) WFF HW RADAC - Impact prediction data
(5) WFF Camera Stations - Documentary
(6) WFF Surveillance Aircraft - Ship Traffic Data
(7) WFF/NASCOM Communications - RSO voice, Countdown/Radar phasing
(8) Bermuda Radar - Vehicle position
(9) Bermuda Telemetry - Vehicle Telemetry Data
(10) Bermuda Command System - Command/Destruct
(11) Weather Constraints

6. Safety Analysis Report

a. Introduction - The purpose of this section is to present a baseline of the public risks for orbital launches from the WFF. The generic risk assessment presented herein is based on the facility's experiences, current commercial launch vehicle characteristics and experiences of the RTI staff. It must be noted that the WFF and other ranges adopted a FTS or "Command Destruct" philosophy in the early 1960's.

This philosophy has always assumed that the Flight Termination System (flight and ground components) provides an acceptable control methodology to prevent unacceptable public exposure from the launch of vehicles. Hence:

(1) Most public risk studies performed by the ranges are based on the assumption that the FTS prevents unnecessary public exposures.
(2) The reliability of the FTS (not the reliability of the launch vehicle) was assumed to be the controlling factor in assuring that public exposures did not occur.
(3) The FTS is utilized to prevent launch vehicles from exposing the public to risks from an errant vehicle and to disperse vehicle propellants in the event of a launch failure.

(4) As shown later, the public risks are primarily controlled by FTS system reliability (not launch vehicle failures) as assumed by the launch ranges.[23]

b. WFF Launch Experience - Following is a brief discussion of the WFF experiences in providing range safety protection during vehicle launch operations:

(1) The WFF has been conducting launches of various rockets and other vehicles since the mid 1940's. Most of the procedures and public safety criteria utilized by the WFF were developed over years of experience. The procedures and criteria for public safety that are utilized to protect the civilian community were evaluated by the Range Commander's Council and the subordinate Missile Flight Safety Group in the early 1960's, in which WFF played an active part.

The WFF has conducted the first launch of most of the research and development rockets used to determine and evaluate the effects of the natural environment on launch vehicles and spacecraft and to increase the knowledge of the Earth's upper atmosphere and the near space milieu. Approximately 2,500 of these types of launches have been performed over the last 30 years (1959 - 1989) by the WFF. The launching of the Scout vehicle for the purpose of placing spacecraft in orbit began in the early 1960's.

Flight safety rules were established for these missions, as well as the design specifications for the flight safety systems utilized to provide public protection.

(2) The Range Safety system at the WFF has accommodated only a few programs requiring destruct systems. These included the Scout, Aerobee, Athena and the Black Brant series of launch vehicles. Out of approximately 200 launches of vehicles (equipped with a FTS), only two reported cases involved an off-range impact.

These occurred during the early stages of the Aerobee program, and resulted in no property damage or injury to people (impact was in the water).

(3) Flight Termination System (FTS) Reliability -The actual flight history reliability for approximately 200 launches shows that no FTS failures have been recorded during these launches.

Since there were no recorded failures at WFF of the FTS system, a conservative estimate is to assume that a total FTS failure occurs on any subsequent launch. On this basis, the demonstrated FTS failure probability can be estimated to be 1/200 or $5x10^{-3}$ with high confidence and the FTS reliability is then; 1-1/200 = 0.995.

c. Public Exposures to WFF Space Launches

(1) Public Hazard Event Tree - The events required for an exposure of the public to a hazard from a space vehicle launch are depicted in **Figure 22**[23]. The event tree shown illustrates the approximate probabilities and conditional events required to expose the public to a launch vehicle failure.

(2) Launch Vehicle Failure Probability/Reliability -The historical reliability and failure rates for the planned commercial launch vehicle (Scout) is shown below in **Table 7**[23]:

TABLE 7. SCOUT LAUNCH VEHICLE RELIABILITY

Phase	Launches	Failures	Reliability %	Failure Rate %
Prior to Recertification (Dec. 1963)	23	10	66.5	43.5
Since Recertification (Dec. 1963)	89	4	95.5	4.5
Overall	112	14	87.5	12.5

The Scout launch vehicle has an overall reliability record of 87.5%. This record covers all launches of all Scout configurations, including development flights, since July 1960. Since the completion of the recertification program in December 1963, the Scout vehicle has demonstrated a reliability of 95.5%. The reliability of commercial launches is expected to continue at a comparable level since the same manufacturing, processing and launch specifications will be utilized. For Event #1 on the event tree, it can be assumed that approximately 95.5% of all Scout space launches are successful. This ignores those launches prior to recertification.

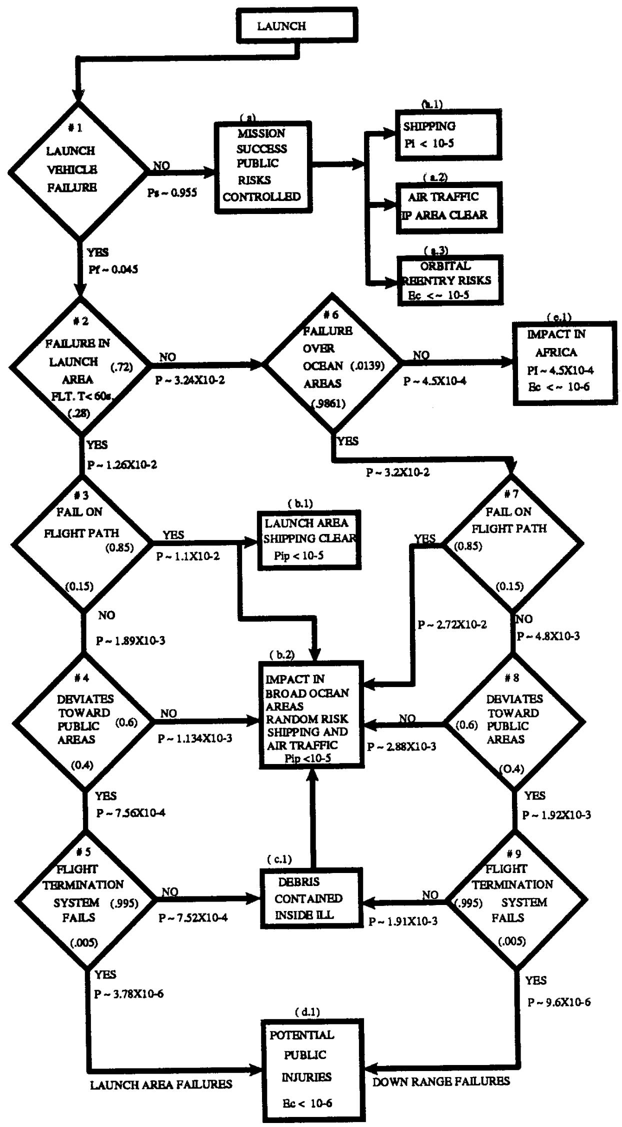


FIGURE 22. PUBLIC LAUNCH EVENT HAZARD TREE

A successful launch results in booster stages and other discarded debris impacting within planned areas and the eventual decay from orbit of all hardware placed in earth orbit. Shown by event tree boxes (a-a.3) are the results and estimated exposure levels for shipping and reentering debris. Planned Air Traffic exposures (a.2) are assumed to be less than 10^{-7}, since the FAA clears air traffic from all impact areas.

Approximately 4.5% of all Scout launch vehicles have failed since recertification and none of these failures occurred during the early launch phase, i.e., 0 to 60 seconds after launch. A conservative approach, however, would be to assume that the failure probability is evenly distributed over the thrusting periods of the solid rocket motors. On this basis, the conditional probability of a failure during the first 60 seconds is 60 seconds/215.6 seconds which equals ~0.28 or 28%. The remaining 72% of the launch failures occur downrange from the launch site and are controlled by Events #6 and #7. The conditional probabilities estimated at each event block are shown in parenthesis within the event block. Of those failures that do occur in the launch area, experience shows that approximately 85% of all launch vehicle failures occur on the original flight path (Event #3). Failures of the propulsion system(s) normally predominate the failure modes. Loss of thrust, loss of thrust vectoring, propulsion system explosions and vehicle structural failures due to turns result in little displacement from the original flight path. In many of these failures, complete destruction of the launch vehicle occurs before flight termination commands can be issued. The results of such failures pose a significant hazard to shipping near the launch site (b.1). Launch hazards to shipping and boating interests are controlled by surveillance out to a range of approximately 100 miles, depending upon the launch vehicle.

Hazardous areas are determined which show the permissible ship and boat locations and density to assure that the probability of impact on a ship or boat is less than 1×10^{-5}. Should failure and impact occur beyond the cleared shipping areas (b.2), studies have shown that shipping densities are such that the impact probabilities in the broad ocean areas are low and the probability of an impact is less than 1×10^{-5}.

Should the vehicle deviate from the flight path (3), the deviation can be in any direction. For WFF launches, approximately 60% of such failures would remain over the broad ocean areas and approximately 40% would be distributed toward populated areas protected by impact limit lines (Event #4). For those not deviating toward public areas, the outcome, (b.2), would result in little public risk whether or not destruct action is taken.

Launch vehicles that deviate toward public areas protected by impact limit lines will be destroyed by the Range Safety Officer, unless a FTS failure occurs (Event #5). Shown previously, the estimated reliability of the FTS is > 0.995 for redundant systems as utilized on the commercial launch vehicles and the probability of FTS failure is $< 5 \times 10^{-3}$. If the

FTS operates properly, all debris is contained inside the ILL and the public risks are essentially the same as result (b.2). As shown, the probability of public exposure near the launch area resulting from these failure events, including FTS failure, is ~$3.78x10^{-6}$. The public risks resulting from this sequence of events will be examined in a later section; however, with an exposure probability this low, the resulting (d.1) casualty expectancy (E_c) will be less than 10^{-6} in all but a most unusual circumstance.

Launch vehicle failures occurring after 60 seconds in flight may fail over the broad ocean areas being crossed or during the overflight of Africa (Event #6).

Those which fail over the ocean follow Events #7-#9. The principal difference for failures occurring in this event sequence is that the conditional probability of reaching land is lower (Event #8) and decreases rapidly with time of flight.

The alternative conditional failure probabilities in Event #6 were derived based on the fact that the dwell time while crossing Africa is less than 3 seconds for a Scout launch vehicle which typically thrusts for approximately 215.6 seconds. Hence, the conditional probability for failure during this crossing is 3/215.6 or .0139 and, therefore, 0.9861 of such failures would normally occur over the broad ocean area. This results in a probability of impact in Africa (e.1) of approximately $4.5x10^{-4}$ and an estimated E_c that is less than 10^{-6}.

d. Launch Vehicle Debris Hazards - The hazards to persons and property are a function of the debris generated by the launch vehicle. Launch vehicle debris hazards vary as a function of destruct action, vehicle failure modes and time in flight of the occurrence.

Debris are normally classified by ballistic coefficient, area, weight and number of pieces per category. Debris characteristics for the proposed Scout commercial launch vehicle are shown in **Table 8**[23] below:

TABLE 8. TYPICAL SCOUT DEBRIS CHARACTERISTICS

Flight Phase	Number Fragments	Lethal Areas (ft.^{2})
Launch Phase	1,420#	5,851*
Overflight Phase	284#	1,000*

* Estimated lethal area

e. Launch Area Public Risk Assessment

(1) The risk of a launch area off-range impact for commercial ELVs (specifically Delta II) is currently being evaluated at the WFF. These studies will aid in the determination of the public risks associated with the proposed commercial launch operations for the Delta II vehicle. The following assessment provides a gross (but conservative) estimate of the public risk for Scout ELV launches from the WFF. The mathematical models necessary to perform a more detailed safety analysis for ELV launches that fail and have a subsequent FTS failure do not exist. RTI has computed several estimates of the worst case risks, however, without sophisticated math models these estimates cannot be fully verified.[23]

(2) An abnormal ELV that does not break up on the flight path has the potential for exposing the public to impact and debris hazards for thousands of miles in any direction should the FTS fail. The probability of public exposure, however, decreases as a function of the square of the range from the launch point. Hence, the probability of impact at 10 miles is 100 times greater than the probability at 100 miles and 10,000 times greater than an impact at 1,000 miles. Therefore, if the probability of impact at 10 miles is 10^{-3}, the probability at 100 miles is 10^{-5} and at 1,000 miles is 10^{-7}.

(3) The population density for the local area surrounding the WFF is shown by **Figure 23**[24]. This figure illustrates the 1988 population centers and densities within 20 miles of the proposed commercial launch site. The maximum population densities are typically between 100 & 1,000 persons per square mile.

The normal risk measure utilized for judging public risk from the launch of space vehicles is called Casualty Expectancy (E_c). This term is the product of the probability of a public exposure from launch vehicle debris and the total public population exposed to the debris hazard. The equation most used is expressed as:

$$E_c = P_i \times LA \times P_d$$

where P_i is probability of debris impact in a specific public area, LA is the lethal area of the debris impacting in that public area and P_d is the population density for the exposed area defined. The probability of impact (P_i) in the general public areas near the launch site is approximately 3.78×10^{-6} based on the event tree shown in **Figure 22**. The Scout launch vehicle poses the largest fragment debris hazard of the current vehicles being launched from the WFF. From the table above, it was shown that a Scout during it's launch phase will produce an estimated 1,420 fragments and a lethal area of approximately 5,851 sq. ft.. As an example of the launch area risks, it is assumed that approximately 1,420 fragments are generated in a Scout accident at an altitude and velocity that produce a fragment hazard area of 3 miles in diameter at a threat range of less than 20 miles.

A typical debris area for an impact at ranges less than 20 miles is

shown as an overlay on **Figure 23**[23].
The area of a circle 20 miles in radius is 1,256 sq. miles of which 40% or 502 sq. miles corresponds with the off-range events from **Figure 22**. A Scout debris area of 3 miles in diameter is equal to 7.1 sq. miles. Since the debris can impact in only one 7.1 sq. mile area for any given failure, the average P_i for the region is equal to: $(3.78x10^{-6})x(7.1/502)= 5.35x10^{-8}$. A worst case estimate of the casualty expectancy, E_c, can be determined by assuming that all the population in the region is concentrated in one 7.1 square mile debris area. On this basis:

$P_i = 5.35x10^{-8}$ for any debris impact area within 20 miles
LA = 5,851 sq. ft.
P_D max = 1,000 persons/sq. mi.

Therefore, the estimated maximum E_c is approximately $1.12x10^{-8}$ for any off-range impact in populated areas of this region. An impact in populated areas is very unlikely, however, should it occur, 2 to 5 casualties could occur based on the E_c assumptions above.
(4) Down Range Public Risks - These risks, which are associated with the vehicle IIP being greater than ~ 20 miles and prior to infringing on a downrange landmass, have not been computed for this assessment. Since these risks are so significantly less than either the launch area or downrange overflight risks, their contribution to this assessment is insignificant.
(5) Overflight Hazards - In order to place satellites in orbit from the WFF, the Scout flight trajectory crosses Africa prior to achieving orbital injection velocity (during fourth stage burn). The typical African overflight region for Scout missions is shown in **Figure 24**[23]. The population density for the overflight corridor is on the average less than 50 persons per square mile with brief exposures to densities between 100-300 persons/square mile, as shown.
African overflight azimuths included are typically between 90^0-129^0 (with launch azimuths from 109^0-126^0 being restricted). If the failure rate of the Scout vehicle were uniformly 0.00021 failures per second (historical failure probability of 0.045 divided by 215.6 seconds of burn operation), the debris area assumed to be approximately 750 square feet (based on fourth stage and payload fragments), the population density as stated above (50 persons/square mile) and the dwell time over Africa is ~ 3 seconds, then an estimated E_c can be determined as follows:

E_c = Pf x Dwell Time x LA x Pd
$E_c = 2.1x10^{-4}$ x 3 x 750 x $50/5280^2$
$E_c = 0.847x10^{-6}$

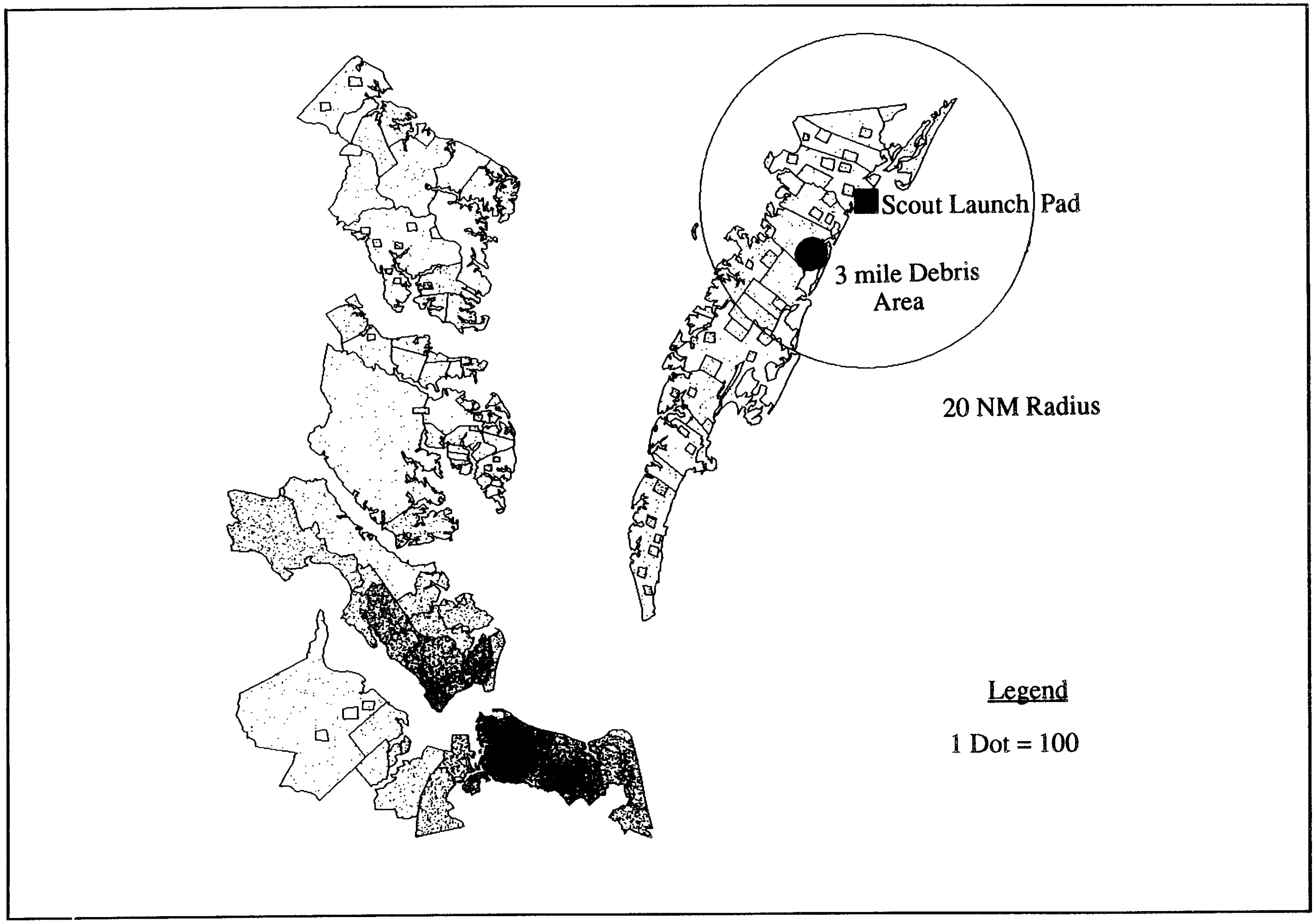


FIGURE 23. RESIDENTIAL POPULATION DENSITY

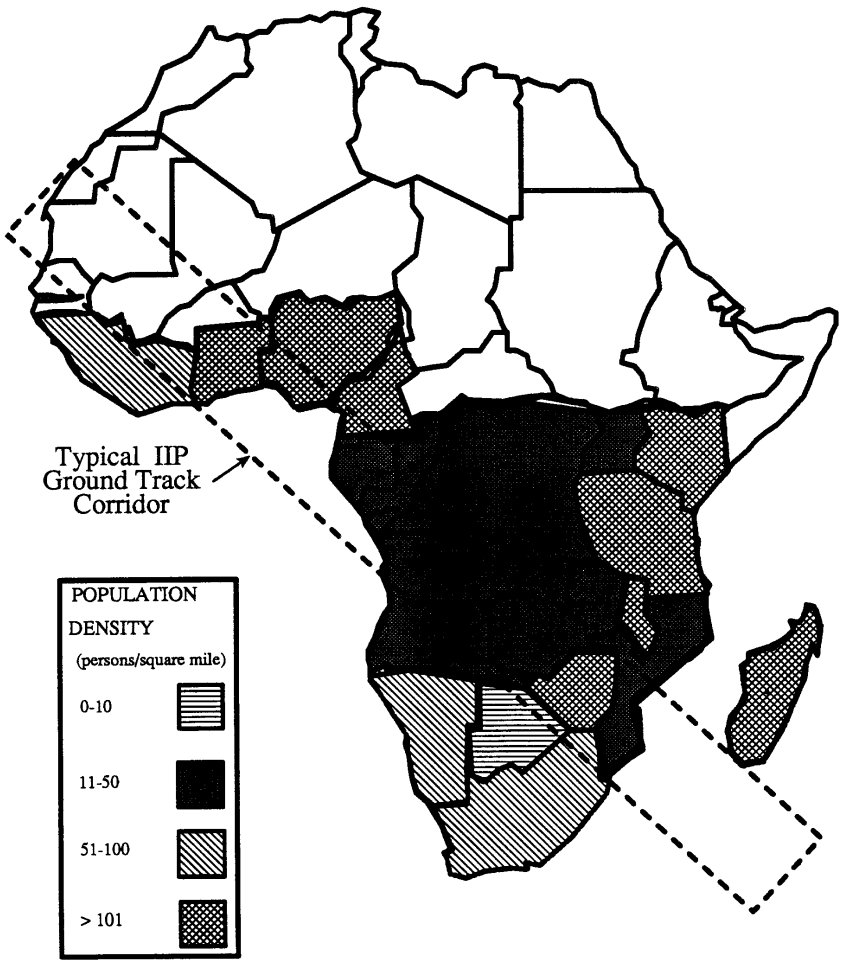


FIGURE 24. AFRICAN OVERFLIGHT CORRIDOR

f. Summary Risks - As shown in this section, the public risks from Scout launches from the WFF are estimated to be approximately one casualty per million launches. More detailed analyses of these risks will typically yield lower estimated public risks. One must be cautious in interpreting these estimates, since the potential for injuries and/or casualties from a single Scout accident can affect numerous persons, although the likelihood of such an occurrence is extremely low.

E. SUMMARY - The WFF baseline assessment follows:

1. Trajectories - Launch azimuths for orbital vehicles (Scout) are normally limited to those between 90^0 and 129^0 azimuth with impact ranges for the third stage of less than approximately 3,500 miles; however, launches outside these limits may be allowed if adequately justified. Sounding rockets are restricted to launch azimuths of from 90^0 to 165^0 and elevation angles of from 80^0 to $>84^0$.

2. Flight Termination System - The WFF requirements, procedures and systems provide a satisfactory method of providing public protection from errant vehicles.

3. Flight Safety Procedures & Data Systems - The WFF public protection procedures and data systems provide assured public protection for off-range events.

4. Staffing - The WFF safety staff is well qualified and the Range Safety Officer training process is complete and comprehensive. A major concern exists in the WFF safety staffing levels necessary to support commercial launch activities. Current levels do not appear adequate to support this program.

5. Instrumentation - Tracking radars and telemetry capabilities exist from lift-off until orbital insertion for the Scout vehicle, or until impact for sounding rockets (depending upon vehicle, trajectory and safety requirements). Command destruct capabilities exist until stage 3/4 separation for the Scout and until impact for sounding rockets that require a FTS. Instrumentation limitations may be expanded by the use of mobile units and the instrumentation of other agencies. It is anticipated that any additional requirements for instrumentation/other resources over and above what is normally provided by WFF would be funded by the commercial user.

6. Vehicle Size - The WFF can accommodate any sounding rockets in the present inventory as well as a typical Scout size launch vehicle. However, investigations are underway to determine if a scaled down Delta class vehicle could be launched from this site and meet existing safety criteria.

REFERENCES

1. NASA, A Guide to NASA Wallops Flight Facility, Undated, Wallops Flight Facility, Wallops Island, VA, 23337
2. NASA, NASA Sounding Rocket and Balloon Program Schedule, March 1989, Wallops Flight Facility, Wallops Island, VA, 23337
3. NASA, Provided by Wallops Flight Facility Personnel, 1988, Wallops Flight Facility, Wallops Island, VA, 23337.
4. NASA, Space Utilization Handbook, June 1987, Wallops Flight Facility, Wallops Island, VA, 23337
5. NASA, Instrumentation Handbook, Vol. I, Radar Facilities and Systems, March 1983, Wallops Flight Facility, Wallops Island, VA, 23337.
6. NASA, Instrumentation Handbook, Vol. III, Data Systems and Facilities, December 1986, Wallops Flight Facility, Wallops Island, VA, 23337.
7. NASA, Instrumentation Handbook, Vol. VI, Optical and Photographic Systems, September 1979, Wallops Flight Facility, Wallops Island, VA, 23337.
8. NASA, Range Operations Directive for the Air Force Scout, June 1985, Wallops Flight Facility, Wallops Island, VA, 23337.
9. NASA, Instrumentation Handbook, Vol. II, Telemetry Facilities and Systems, January 1979, Wallops Flight Facility, Wallops Island, VA, 23337.
10. NASA, Instrumentation Handbook, Vol. IV, Communications Facilities /Systems, October 1984, Wallops Flight Facility, Wallops Island, VA, 23337.
11. "Forecast and Inventory: Space", Aviation Week and Space Technology, March 1988.
12. NASA, Safety Plan for Handling/Transfer of Hydrazine (N2H4) for Scout, Wallops Flight Facility, Wallops Island, VA, 23337.
13. NASA, Air Force Scout Ground Safety Plan, 1985, Wallops Flight Facility, Wallops Island, VA, 23337.
14. U.S.A.F., NASA/DOD Scout Flight Termination System Report, Rev. L, December 1981, Directorate of Safety, Vandenberg AFB, California, 93437.
15. NASA, NASA Sounding Rocket Chronological Launch Data and Failure Histor y, 2 February 1989, Wallops Flight Facility, Wallops Island, VA, 23337
16. NASA, Wallops Flight Facility Sounding Rocket Program, June 1978, Wallops Flight Facility, Wallops Island, VA, 23337
17. NASA, Black Brant X: The Low Cost Development of an Advanced Sounding Rocket System, not dated, Goddard Space Flight Center, Greenbelt, Maryland, 20771
18. NASA, Range Safety Handbook, Goddard Space Flight Center, GHB 1771.1, September 1984, Wallops Flight Facility, Wallops Island, VA, 23337.
19. NASA, Range Safety Policies and Criteria for Goddard Space Flight Cente r (GSFC)/Wallops Flight Facility(WFF), GMI 1771.1, September 1984, Wallops Flight Facility, Wallops Island, VA, 23337.
20. NASA, Flight Safety/Range Safety Officer Training, 1985, Wallops Flight Facility, Wallops Island, VA, 23337.
21. NASA, Instrumentation Utilization for Risk Control of Safety Operations , Undated, Wallops Flight Facility, Wallops Island, VA, 23337.
22. NASA, Aircraft Hazards Due to Rocket Operations, August 1983, Wallops Flight Facility,

Wallops Island, VA, 23337.
23. Personal knowledge and experience of the following RTI staff: Mr. Loyd C. Parker, Mr. Jerry D. Watson, Mr. James F. Stephenson and Mr. Abe Spinak.
24. SLP, Atlas graphics, Research Triangle Institute, Cocoa Beach, Florida 32931.
25. NASA, Scout Launch History, Wallops Flight Facility, Wallops Island, VA, 23337.
26. NASA, Report on Establishing a Uniform Hazard Criteria and Operating Procedure for Aircraft, October 1967, Wallops Flight Facility, Wallops Island, VA, 23337.
27. NASA, Scout AF Satellite Flight Safety Plan, 1985, Wallops Flight Facility, Wallops Island, VA, 23337.
28. NASA, Emergency Plan for the Scout Vehicle, 1985, Wallops Flight Facility, Wallops Island, VA, 23337.
29. NASA, Range Safety Support Request, 1985, Wallops Flight Facility, Wallops Island, VA, 23337.
30. NASA, Test Directive for Black Brant X, May 1986, Wallops Flight Facility, Wallops Island, VA, 23337
31. NASA, Wind Weighting Data Package for Black Brant X, Nov 1989, Wallops Flight Facility, Wallops Island, VA, 23337