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A SUGGESTED CLASSIFICATION SYSTEM
FOR
STANDARD ON-ORBIT SHUTTLE FLIGHT PHASES

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1. INTRODUCTION

The great variety of payloads and flight objectives will necessarily result in a considerable diversity of Shuttle flight profiles. This is particularly true of the on-orbit portion of flight (i.e., between External Tank separation and atmospheric entry) to which this report is addressed. The definition of more or less standard flight segments or phases, representing flight profile components which can be combined in various sequences to satisfy particular objectives, is a practical necessity for simplifying operational procedures and for minimizing the cost of flight planning, software development, and training.

The concept of dividing a flight profile into a series of distinct segments or phases for the purposes of analysis and training is by no means new or unique to the Shuttle. Nor, for that matter, is the principle of phase standardization. For example, the rendezvous phase has been treated as a discrete flight segment for analysis and training purposes in all manned space flight programs since Gemini. From the Gemini, Apollo, Skylab, and ASTP programs there evolved a farily standard rendezvous procedure whose prime characteristics have been incorporated into current plans for a standardized Shuttle rendezvous procedure.

The new elements that will be introduced into flight planning, training, and software requirements in the Shuttle operational era therefore do not include the basic principles of flight profile segmentation nor of segment standardization. Instead, the critical new elements are (1) a greater variety of generic segment types that may be incorporated into a given flight profile, (2) a greater variability of the order in which segments may be combined to construct a particular flight profile, and (3) a greater variation of detail within a given generic segment type. All of these variations arise basically from Shuttle payload characteristics. They are manifested in a number of ways, including changes in the Shuttle configuration from one flight to another.

Item (3) above is particularly troublesome and, in relation to flight phases involving extensive interaction between Shuttle and payload, has given rise to serious questions regarding the feasibility of defining phase types that are "standardized" in any meaningful sense. The very difficulty of the problem, however, emphasizes the need for a solution. The greater the diversity of operational requirements, the greater the need to classify them in terms of their generic features.

Early attempts at defining standard flight phases for the Shuttle (e.g., References 1 and 2) have been helpful but have been received with only limited enthusiasm by the broad community of specialists involved in mission analysis, flight planning, training, and flight operations. This lack of enthusiasm is due partly to different opinions regarding the essential elements of a flight phase. Some analysts think of flight phases in terms of trajectory segments, others in terms of procedural activities, and yet others in terms of flight software requirements. All of these viewpoints are valid, and must be accommodated within the framework of any useful classification system.

Other differences of opinion are related to the proper scope of a "standard" flight phase. Take the case of a multi-maneuver orbital transfer sequence as an example. Some analysts argue that since the various maneuvers and the intervening coast periods are related in such a manner that the whole sequence must be treated as an entity for the purpose of maneuver targeting, the entire sequence properly should be regarded as a single phase. Others point out that such a sequence may involve several Orbital Maneuvering System (OMS) firings that are, from a procedural viewpoint, identical with each other and with engine firings required in entirely different flight sequences. Therefore, they argue, the execution of an OMS maneuver (no matter how targeted) should represent a standard flight phase. Still other analysts point out that even a standard OMS maneuver sequence is compounded of other elements (e.g., a pre-ignition rotational maneuver and an inertial attitude hold) which are required for many purposes not associated with OMS firings, and that logically they should be identified as standard flight phases.

Again, all of these arguments are valid and must be accommodated within any useful flight phase classification system. It has long been recognized that some kind of "phase within phase" structure is an implicit requirement in any logical phase standardization scheme. However, previous attempts at defining standard flight phases for the Shuttle have failed to delineate such a structure in an explicit manner. This has often resulted in a sense of ambiguity as to how the various phases relate to each other in a practical sense.

2. SUGGESTED PHASE CLASSIFICATION STRUCTURE

Figure 1 depicts a suggested classification structure for Shuttle on-orbit flight phases that has been devised with the intent of resolving some of the ambiguities previously discussed. This structure is preliminary and incomplete; however, its basic features are believed to provide a reasonable framework within which an orderly, unambiguous, and comprehensive definition of standard flight phases can be developed.

Before entering into a detailed discussion of the proposed classification system, working definitions of some of its elements will be helpful. The primary distinguishing characteristic of a flight <u>phase</u> is taken to be that it spans a definite, uninterrupted time interval during which the flight system* is devoted to the attainment of a specific objective (which may be to maintain itself in a specified state). A phase <u>type</u> is distinguished by the generic description of the objective to be achieved. As illustrated in Figure 1, phase types are grouped into ordered <u>classes</u> which reflect a hierarchy of objectives. There may be several <u>versions</u> of a given phase type, reflecting alternate methods of achieving the objective or variations in the definition of the objective, such as might be required by different payload characteristics. Possible versions of the various phase types are not delineated in Figure 1. Such an undertaking is beyond the scope of this report.

The first step in the formulation of the structure shown in Figure 1 was to make a list of on-orbit phase types that suggested themselves as logical flight segments on the basis of (1) identifiable objectives common to all or many flight profiles, and (2) distinct requirements and constraints in relation to flight safety, maneuver targeting, flight crew activities, flight software, and flight hardware. Having done this, the problem of defining the relationships between the various phses types was addressed. Taking each phase type in turn, the question was asked: "Which of the other flight phase types might be logical components of this phase?" The phase

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*In this context the flight system consists of the Shuttle, the flight crew, and the payload (if appropriate).

CLASS	PHASE TYPE		ON-ORBIT PHASE COMPONENTS																					
			SECONDARY PHASES									TERTIARY PHASES						QUATERNARY PHASES						
	ID	NAME	RENDEZVOUS BRAKING	SHORT-RANGE STATIONKEEPING	LONG-RANGE STATIONKEEPING	PAYLOAD GRAPPLING	PAYLOAD MANIPULATION	PAYLOAD RELEASE	DOCKING	UNDOCKING	DEPARTURE	EXTRA-VEHICULAR ACTIVITY	PLATFORM ALIGNMENT	GEOCENTRIC ORBIT DETERMINATION	RELATIVE ORBIT DETERMINATION	TRANSLATIONAL MANEUVER	FLUID DUMP/VENT	ROTATIONAL MANEUVER	INERTIAL ATTITUDE HOLD	LOCAL VERTICAL ATTITUDE HOLD	TARGET TRACKING	THERMAL CONDITIONING	ATTITUDE DRIFT	POWERED FLIGHT STEERING
PRIMARY		Preflight*																						
		Launch*																						
		ORBITAL TRANSFER											◑	◑		●	○	○	○	○	○	○	○	◑
		ORBIT DWELL										○	○	○		○	○	○	○	○	○	○	○	○
		RENDEZVOUS	◑												●	●		○	○	○	○			◑
		CONVOY		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
		DEORBIT											◑	◑		●	○	○	○	○	○	◑		◑
		Entry*																						
		Approach and Landing*																						
		Postflight*																						
		Ferry*																						
SECONDARY**	BRK	RENDEZVOUS BRAKING													◑	●		○	○		○			
	SSK	SHORT-RANGE STATIONKEEPING										○						○	○	○	○			
	LSK	LONG-RANGE STATIONKEEPING											○	○	◑	○	○	○	○	○	○	○		
	PLG	PAYLOAD GRAPPLING													○	○		○	○	○	○			
	PLM	PAYLOAD MANIPULATION										○						○	○	○			○	
	PLR	PAYLOAD RELEASE														○		○	○	○	○		○	
	DOK	DOCKING													○	○		○	○	○	○			
	UDK	UNDOCKING														○		○	○	○	○			
	DEP	DEPARTURE													○	○		○	○	○	○			
TERTIARY**	EV	EXTRA-VEHICULAR ACTIVITY																○	○	○	○		○	
	AL	PLATFORM ALIGNMENT																○	○	○	○			
	GD	GEOCENTRIC ORBIT DETERMINATION																○	○	○	○	○	○	
	RD	RELATIVE ORBIT DETERMINATION																○	○	○	◑			
	XM	TRANSLATIONAL MANEUVER																○	○	○	○			○
	FV	FLUID DUMP/VENT																○	○	○	○	○	○	
QUATERNARY**	R	ROTATIONAL MANEUVER																						
	I	INERTIAL ATTITUDE HOLD																						
	L	LOCAL VERTICAL ATTITUDE HOLD																						
	T	TARGET TRACKING																						
	C	THERMAL CONDITIONING																						
	D	ATTITUDE DRIFT																						
	S	POWERED FLIGHT STEERING																						

* NON-ORBITAL PHASES SHOWN ONLY FOR REFERENCE

** ON-ORBIT PHASES ONLY

LEGEND

● ESSENTIAL
◑ PROBABLE
○ POSSIBLE

Figure 1. Suggested Phase Classification Structure

types were then grouped into the ordered classes shown in Figure 1 by applying the criterion that a phase can be a component of another phase only if it (the component) belongs to a subordinate class. It was also assumed that no phase would be allowed to overlap (i.e., extend beyond the beginning or the end of) any other phase of equal or superior rank.

The primary phases constitute the major segments of a flight profile. Any Shuttle flight can be described, in a gross sense, by an appropriately ordered combination of contiguous primary phase types. The non-orbital primary phases listed in Figure 1 (Preflight, Launch, Entry, etc.) are shown only for the purposes of placing the orbital phases in context relative to the total flight profile.

Taking the broad view that payloads attached to the Shuttle by the Remote Manipulator System (RMS) are separate vehicles, it turns out that all of the secondary phase types are characterized by some sort of multi-vehicular involvement. This was not a criterion for including a phase type in the secondary class; rather, it is a characteristic that was observed after the classification was accomplished. Likewise, it was observed after the fact that all of the fourth-order (quaternary) phase types are devoted to some kind of vehicle attitude control. No single distinquishing characteristic is obvious in the case of the third-order (tertiary) phase types.

It may appear to some readers that a number of important on-orbit flight phase types are conspicuous by their absence from Figure 1. The provisional structure is acknowledged to be incomplete, and undoubtedly there are omissions resulting from oversight. However, there were several categories of inflight activity that were duly considered and judged (tentatively, at least) not to constitute "standard phase types" within the meaning of the proposed definition. For example, Figure 1 does not include any phase types identified with contingency procedures, per se. While there is no doubt that procedures will be formulated to deal with abnormal flight situations, there is some question as to whether such procedures properly can be classified as "standard" flight phases. Even if they should be, in some cases at least they may represent nothing more than a special version of a nominal phase type. For instance, the procedure for aborting from orbit might be represented by a particular version of the Deorbit phase type.

It may also be noted that there is no phase type in Figure 1 which is identified specifically with docked flight operations. A docked configuration is taken to be one in which some vehicle is securely attached, by means of docking adapters, to a payload or mechanism secured within and extending from the Shuttle cargo bay, with sufficient rigidity to allow the whole assembly to be maneuvered (within appropriate acceleration limits) as a single spacecraft. It was not possible to formulate a logical definition of a "docked flight" phase type that would be consistent with the overall classification system, because it is conceivable that docked flight operations could encompass one or several of the primary phase types (Orbital Transfer, Orbit Dwell, Rendezvous, or Convoy) wherein the docked assembly would be treated as a single vehicle. Therefore, the rationale was adopted that "docked flight" characterizes a particular condition or configuration of the Shuttle, rather than a standard flight phase.

Payload checkout and activation operations constitute a major category of activities which were considered but not included in the list of phase types. The nature and scope of these activities are so diverse (and often so disjoint in a temporal sense) that it did not seem possible to formulate any meaningful generic definition of a "payload checkout" or a "payload activation" phase type. It was concluded that payload checkout and activation operations would best be regarded as requirements superimposed on the flight phase structure, rather than as constituent elements of it.

Likewise, there are no phase types shown in Figure 1 which are devoted to personal activities of the flight crew (sleeping, eating, etc.). This does not reflect any lack of appreciation for the importance of maintaining the physiological condition and efficiency of the flight crew. At one time, activities of this nature were included in the list of secondary phase types. Their removal from the list was based on the reasoning that if the flight crew were large enough to support two-shift operations, such functions would not necessarily conflict with other activities. Possibly they should be reinstated as standard phase types for flights involving smaller crews; however, the current rationale (again) is that such activities would best be treated as superimposed requirements[*], rather than as constituent elements of the flight phase structure.

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[*] As reflected, for instance, in a timeline for each flight crew member that addresses all of his activities. Such timelines are essential to insure that the necessary human skills are available as required for all fight operations.

3. PROVISIONAL PHASE TYPE DEFINITIONS

Sections 3.1 through 3.4 contain provisional definitions of the on-orbit phase types listed in Figure 1. These definitions are preliminary and contain only enough detail to identify the scope and major characteristics of the phase types. They are presented with the intent of clarifying their relationships with one another in the overall structure of the proposed classification system.

3.1 PRIMARY PHASES

3.1.1 Orbital Transfer

The objective of this type of phase is to transfer the Shuttle from one orbit to another. It may contain one or several translational maneuvers. It begins with the preparations for the first maneuver, and ends with the completion of the final maneuver that inserts the Shuttle into the target orbit.

The maneuver targeting techniques and operational procedures used in the initial portion of some rendezvous sequences (prior to acquisition of the target vehicle by the onboard navigation sensors) are essentially the same as those employed in certain payload delivery sequences that do not involve rendezvous. Therefore, it is believed that this phase type should include any orbit-modification maneuver sequence -- with the exception of deorbit sequences, which fall in a special category -- whose targeting normally does not depend on vehicle-to-vehicle relative navigation measurements, even if rendezvous is the ultimate objective.

Typical objectives of a one-maneuver orbital transfer phase include orbit circularization, attainment of a specified orbit period, adjustment of apsidal altitudes, etc. The objective of a multi-maneuver sequence might be to place the Shuttle in a specified sun-synchronous orbit. A typical objective in the case of flights involving rendezvous would be to place the Shuttle in a coelliptic orbit (relative to the ground-estimated orbit of a target satellite) with the proper differential altitude, phase angle, and lighting conditions to facilitate target acquisition by the rendezvous navigation sensors.

3.1.2 Orbit Dwell

The objective of an orbit dwell phase is to maintain the Shuttle in a nominal free-fall orbit for the purpose of satisfying flight requirements other than (1) necessary coast intervals between maneuvers in a rendezvous or an orbital transfer sequence, (2) attainment or maintenance of a defined spatial relationship with reference to another orbiting vehicle, or (3) those associated with the deorbit phase. If appropriate, it may include the execution of small corrective maneuvers designed to negate the effects of orbit insertion errors, aerodynamic drag, fluid venting, etc. It begins with insertion of the Shuttle into the nominal orbit, and ends when the appropriate flight requirement is satisfied. Typical requirements include the maintenance of zero g for a space processing experiment, and the maintenance of a specified ground track for the purpose of gathering earth resources data.

3.1.3 Rendezvous

The objective of a rendezvous phase is to place the Shuttle in a stationkeeping state relative to a target satellite, by means of rendezvous maneuvers which normally are targeted on the basis of onboard relative orbit determination (rendezvous navigation) measurements. In the case of the standard Shuttle rendezvous sequence described in Reference 3, it would begin after execution of the first NSR maneuver (just prior to initial target acquisition by the star tracker) and would end when the stationkeeping state is achieved. It includes the relative orbit determination phases necessary to target the rendezvous maneuvers, as well as the maneuvers themselves.

A rendezvous braking phase may or may not be included as a component of a rendezvous phase, depending on whether the immediate objective is to attain a close-range stationkeeping position or a long-range (stable orbit) standoff position. In the latter case, if the ultimate objective is to attain a short-range stationkeeping position (say for the purpose of retrieving or servicing the target satellite), the flight profile would include two rendezvous phases separated by a convoy phase. The second rendezvous phase would begin with the execution of the maneuver to initiate the terminal approach from the stable orbit standoff position.

3.1.4 Convoy

The objective of a convoy phase is to satisfy some flight requirement that involves the Shuttle and another vehicle which is either (a) attached to the Shuttle by means of the RMS, or (b) flying independently in an orbit that is nominally coperiodic and at least nearly coplanar with the orbit of the Shuttle. This phase type encompasses all multi-vehicular orbital operations other than rendezvous. A convoy phase always begins with either (1) the termination of a rendezvous phase, (2) the extraction of a payload from the Shuttle cargo bay, (3) the release of a vehicle from a docking adapter. It always ends with either (1) the stowage of a payload in the Shuttle cargo bay, (2) the establishment of a docked configuration, or (3) the attainment of a safe separation distance between the Shuttle and the other vehicle in diverging orbits.

Typical objectives of a convoy phase include payload deployment, payload retrieval, and maintenance of a stationkeeping relationship between the Shuttle and a free-flying satellite for the purpose of conducting certain types of experiments.

3.1.5 Deorbit

The objective of the deorbit phase is to return the Shuttle to the atmospheric entry interface (400,000-foot altitude) in such a state that its atmospheric maneuvering capabilities will be adequate to achieve a safe landing at a designated site. The deorbit phase normally begins with whatever preparations are appropriate for atmospheric entry, after all orbital flight objectives have been achieved (or abandoned, in the case of abort). It ends when the Shuttle reaches the entry interface altitude. In addition to the deorbit maneuver which initializes the actual entry trajectory, it may include one or more preliminary translational maneuvers designed to control the Shuttle's position and velocity at the entry interface. Usually it will include a thermal conditioning phase sometime before the final deorbit maneuver, so that deterioration of the thermal protection system will be minimized during the subsequent atmospheric deceleration.

3.2 SECONDARY PHASES

3.2.1 Rendezvous Braking

The objective of a rendezvous braking phase it to establish the Shuttle in a short-range stationkeeping state relative to a free-falling satellite. It begins at some point (usually at a range on the order of two miles) on a trajectory targeted to intercept the satellite under favorable lighting conditions, and it ends when the stationkeeping state is achieved. It is characterized by a series of translational maneuvers, usually executed by the Reaction Control System (RCS), which progressively reduce the magnitude of the range rate as the range decreases. General requirements of the rendezvous braking phase include continuous visibility of the target by the Shuttle pilot, and a continuous determination and display of the instantaneous range and range rate.

3.2.2 Short-Range Stationkeeping

The objective of a short-range stationkeeping phase is to satisfy some flight requirement involving the maintenance of a defined spatial relationship* between the Shuttle and a free-flying satellite, at ranges commensurate with the ability of a pilot to control the relative motion between the two vehicles without necessary reliance on navigation sensors and flight software for the calculation of maneuvers. This type of phase is always preceded by a rendezvous braking, long-range stationkeeping, payload release, or undocking phase. It is always followed by a long-range stationkeeping, payload grappling, docking, or departure phase.

Short-range stationkeeping phases are characterized generally by an imminent possibility of physical contact between the Shuttle and the satellite, possible adverse effects on the satellite by fluid venting or thruster firings on the part of the Shuttle, and a requirement for continuous visual observation of the satellite by the Shuttle pilot.

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*This is not restricted to the maintenance of a constant relative position; for example, it might include the execution of a "flyaround" to inspect the satellite.

3.2.3 Long-Range Stationkeeping

The objective of a long-range stationkeeping phase is to satisfy some flight requirement involving the maintenance of a defined spatial relationship between the Shuttle and a free-flying satellite, at ranges sufficiently great to require the aid of navigation sensors to calculate maneuvers designed to control the relative motion of the two vehicles. The navigation sensors do not necessarily have to be carried aboard the Shuttle or its companion satellite; in some cases, for instance, they could be ground radars. This phase type is always preceded by the terminal maneuver of a rendezvous phase or by a short-range stationkeeping, payload release, or undocking phase. It is always followed by a rendezvous, short-range stationkeeping, payload grappling, docking, or departure phase.

Because of the distances involved, long-range stationkeeping phases generally are not characterized by the imminent possibility of collision nor by a requirement for continuous visual observation of the satellite by the Shuttle flight crew. In some cases, however, constraints may be imposed on Shuttle thruster firings and/or fluid venting to minimize the contamination of sensitive instruments aboard the companion satellite.

Typical flight requirements associated with long-range stationkeeping include carrying out certain types of multi-vehicular experiments, escorting a deployed payload to facilitate its retrieval in case it fails to check out satisfactorily, and providing a period of rest for the flight crew between short-range stationkeeping phases.

3.2.4 Payload Grappling

The objective of a payload grappling phase is to establish a physical connection with and mechanical control of a free-flying payload by means of the RMS. Such a phase may involve Shuttle maneuvers and/or the use of systems such as a free-flying teleoperator and devices such as cables and winches to bring the payload within the working range of the RMS. The phase begins with whatever preparations (RMS unstowage, initiation of closure from a stationkeeping position if necessary, etc.) are appropriate immediately before the grappling operation, and it ends when the RMS is securely attached to the payload. A payload grappling phase is always preceded by a short-range or a long-range stationkeeping phase, and always followed by a payload manipulation phase.

Payload grappling phases are characterized by an imminent possibility of collision, possible adverse effects on the payload by fluid venting or thruster firings on the part of the Shuttle, and a requirement for continuous visual observation of the payload by the Shuttle pilot and/or the RMS operator.

3.2.5 Payload Manipulation

The objective of a payload manipulation phase is to satisfy some flight requirement involving the exercise or maintenance of mechanical control over a payload by means of the RMS. This includes operations in which the RMS is used to connect or disconnect the components of a docked vehicle configuration. This phase type always begins either (1) immediately after a payload grappling phase, (2) with the unstowing of a payload from the Shuttle cargo bay, or (3) with the detachment of a payload from a docking adapter. It always ends either (1) immediately before a payload release phase, (2) with the stowing of the payload in the cargo bay, or (3) with the attachment of the manipulated payload to a docking adapter.

Constraints on Shuttle thruster firings usually are necessary to avoid unacceptable mechanical loads on the RMS during payload manipulation. Some payloads will also be sensitive to contamination resulting from thruster firing and/or fluid venting. Usually at least some portions of a payload manipulation phase will be characterized by a possibility of inadvertent physical contact between the payload and the Shuttle that could damage either or both vehicles. Therefore, there may be special attitude control requirements to assure favorable lighting conditions for observation of the payload. There also may be requirements for devices (remote television cameras, special mechanical systems in the cargo bay to aid in the removal and insertion of large payloads, etc.) to supplement the capabilities of the RMS.

3.2.6 Payload Release

The objective of this flight phase type is to release a payload from the RMS in such a manner as to satisfy the particular requirements for initializing free flight of the payload. Such a phase begins with whatever preparations are appropriate specifically for the release operation, and ends with the attainment of sufficient physical clearance between the Shuttle and the payload to permit the Shuttle to be maneuvered more or less as an independent vehicle. A payload release phase is always preceded by a payload manipulation phase, and always followed either by a stationkeeping or a departure phase.

Usually the free-flight initialization requirements will include payload attitude and attitude rate specifications referenced either to a local-vertical or an inertial coordinate system. Flight safety requirements will impose restrictions on the Shuttle-relative translational and rotational motion that is imparted to the payload in the process of releasing it from the RMS. Shuttle thruster firings generally must be restricted to avoid jet plume impingement that would contaminate and/or destabilize the payload. Simultaneous satisfaction of all these requirements may necessitate the use of separation devices such as preloaded springs or payload thrusters, sensitive instrumentation that might include RMS strain gauges and payload-mounted gyroscopes (which conceivably might provide input data to the Shuttle autopilot or to the RMS control software), and special pre-release attitude control procedures.

3.2.7 Docking

The objective of a docking phase is to achieve a secure physical connection between a free-flying vehicle and a payload or mechanism that has been erected or extended to protrude from the Shuttle cargo bay, by means of appropriately-designed docking adapters and without the aid of the RMS. Such a phase is always preceded by a stationkeeping phase. It begins with whatever preparations are necessary immediately before the docking operation. It ends when the physical connection (including fluid and electrical conduits, if appropriate) is complete and secure, and the flight control system is configured for docked flight.

A docking phase usually requires precise translational and rotational control of the Shuttle at least until the time at which actual physical contact between the docking adapters activates some sort of retention device such as a system of capture latches. Therefore, it will not usually involve a free-flying vehicle that is easily contaminated or destabilized by RCS jet plume impingement.

3.2.8 Undocking

The objective of an undocking phase is to separate the Shuttle from a vehicle to which it has been docked, without using the RMS. Such a phase begins with whatever preparations are appropriate and necessary immediately before release of the docking retention mechanism, and ends when sufficient physical clearance is attained to allow the Shuttle to be maneuvered more or less as an independent vehicle. An undocking phase initiates a convoy phase, and is always followed either by a stationkeeping or a departure phase.

3.2.9 Departure

The objective of a departure phase is to terminate a convoy phase by placing the Shuttle in a diverging orbit relative to the convoyed vehicle. The phase begins with preparations for the initial departure maneuver, and ends when (1) the diverging orbit has been established and (2) the distance between the vehicles becomes great enough so that the normal independent functions of both vehicles can be performed without having to consider how the actions of one might affect the other. The latter condition might mean, for instance, that Shuttle thruster firings would no longer be constrained to avoid contamination of sensors aboard a former companion satellite, or that the propulsion system of a just-deployed tug could be armed without fear of damaging the Shuttle in the event of an explosion.

3.3 TERTIARY PHASES

3.3.1 Extra-Vehicular Activity

The objective of an extra-vehicular activity (EVA) phase is to satisfy some flight requirement that necessitates the egress of one or more pressure-suited flight crew members from the habitable environment of the flight system, to return all crew members safely into the habitable environment, and to restore the normal integrity of the environment envelope after completion of EVA. The phase begins with whatever preparations (stabilization of vehicle attitude, donning of pressure suits, etc.) are appropriate and necessary immediately before the EVA. It ends when all EVA participants have returned to the habitable environment, all hatches have been secured, and the pressure suits have been doffed and stowed.

EVA phases are characterized generally by stringent limitations on translational and rotational vehicle maneuvers that might jeopardize the safety of the extra-vehicular crew member(s). RCS thruster firings may be necessary to maintain a stationkeeping position relative to another vehicle and/or to maintain an attitude that will provide adequate lighting conditions in the EVA work area. However, depending on his location, the firing of particular thrusters may have to be inhibited to avoid jet plume impingement on an extra-vehicular crewman.

3.3.2 Platform Alignment

The objective of a platform alignment phase is to determine precisely, by means of star tracker measurements, the orientation of the stable member of one or more of the Shuttle Inertial Measurement Units (IMUs) with respect to an inertial coordinate system, and to re-orient the stable member(s) if necessary. Normally, when at least one IMU is already aligned within reasonable error limits, this is an automatic procedure which is executed under the control of an onboard computer. In such a case, the phase begins when the flight crew issues the appropriate command to the computer, and it ends when the computer signals that the alignment has been accomplished. The length of the phase will depend on the position and orientation of the Shuttle when the alignment command is given, on the number of star trackers that are functioning during the procedure, and possibly on the nature of pre-existing vehicle attitude constraints which might be in force during the alignment.

If none of the IMUs are aligned within reasonable error limits at the beginning of the phase, a preliminary coarse alignment will be necessary. This requires the flight crew to execute a series of manually-controlled rotational maneuvers to point the optical axis of the Crew Optical Alignment Sight (COAS) at recognizable stars. In such a case, the alignment phase begins with the initial rotational maneuver.

3.3.3 Geocentric Orbit Determination

The objective of this phase type is to obtain a series of measurements of one or more observable quantities that can be used to calculate an estimate or to refine a prior estimate of the Shuttle's orbit relative to a geocentric inertial coordinate system. The observations can be made either on the ground or on board the Shuttle. The duration of the phase corresponds to the length of time needed (or available) to acquire an amount of data appropriate for defining the orbit as accurately as desired (or possible). Measurements do not necessarily have to be made continuously or regularly; the phase may encompass two or more periods of essentially continuous observation separated by intervals in which measurements are either impossible or unproductive.

Depending on the type and location of the sensor(s) used, the measurement process may or may not impose computational and/or attitude requirements on the Shuttle. For instance, onboard Doppler measurements will entail on-board data processing and may involve the pointing of a directional antenna at the Tracking and Data Relay Satellite (TDRS). On the other hand, ground radar tracking might be accomplished without imposing any constraints on Shuttle flight activities. However, if the Shuttle is in a low-altitude orbit, its attitude may have to be constrained during the orbit determination phase so that the effects of aerodynamic drag can be computed accurately, especially if the measurements are being made on the ground.

3.3.4 Relative Orbit Determination

The objective of this phase type is to obtain a series of measurements of one or more observable quantities that can be used to calculate an estimate or to refine a prior estimate of the Shuttle's orbit relative to another earth satellite. The measurements are made on board the Shuttle by means of rendezvous radar, a star tracker, and/or possibly other relative navigation sensors. The duration of the phase corresponds to the length of time needed (or available) to acquire an amount of data appropriate for defining the relative orbit as accurately as desired (or possible). Measurements do not necessarily have to be made continuously or regularly; the phase may encompass two or more periods of essentially continuous observation separated by intervals in which measurements are either impossible or unproductive.

Attitude constraints of a more or less stringent character will generally be imposed on the Shuttle, depending on the sensor(s) being used to obtain navigational measurements. Measurements necessarily will be processed by a Shuttle onboard computer, probably in a sequential mode. Typically, relative orbit determination phases will be needed to support rendezvous maneuver targeting, stationkeeping, and other types of multi-vehicular activity.

3.3.5 Translational Maneuver

The objective of this phase type is to effect a change in the orbit of the Shuttle, using translational thrust generated by the OMS and/or the RCS engines to null the components of a velocity-to-be-gained vector that is periodically updated during the maneuver by a powered flight navigation computer program. This does not include small translational maneuvers executed by the pilot, without the aid of navigational software, to control relative motion during short-range stationkeeping, payload grappling, docking, and undocking phases.

The phase begins when the flight crew commands the onboard computer to begin the execution of the appropriate OMS or RCS thrust program, either by accepting the results of a prior onboard maneuver targeting computation or by keying in the ignition time and the ΔV components of an externally-computed maneuver. If the OMS is being used, generally this is followed by a rotational maneuver to the ignition attitude, an alignment check to verify attainment of the correct attitude, arming of the OMS engine(s), and the initiation of powered flight navigation shortly before ignition. After ignition, the computer periodically updates the velocity-to-be-gained vector on the basis of thrust accelerations sensed by the IMU (and maneuver targeting logic such as the Lambert algorithm, if appropriate), issues necessary commands to the OMS thrust vector control and RCS attitude control systems, and issues a command to terminate OMS thrust at the proper time. After OMS thrust termination, the computer continues to calculate residual velocity-to-be-gained vector components, which must be nulled within acceptable tolerances by the RCS thrusters. The phase ends when the OMS engines have been inhibited from further firing, the residual velocity increments have been nulled, and powered flight navigation has been terminated.

Sometimes the maneuver will be executed by the RCS thrusters alone. In such cases, of course, the previously-described operations involving the OMS will not apply. Depending on the situation, a pre-ignition rotational maneuver may or may not be executed to align a particular set of RCS thrusters with the velocity-to-be-gained vector. The RCS thruster firings necessary to null the velocity-to-be-gained vector may be commanded manually by the pilot, or automatically by the computer. The reliance on RCS thrusters alone to perform a translational maneuver may be occasioned by (1) a required velocity increment smaller than can be delivered accurately and safely by an OMS engine firing, (2) vehicle attitude constraints which prevent the orientation of the OMS thrust line in the direction required to accomplish the maneuver, (3) constraints on the magnitude and/or the body-related direction of thrust acceleration, or (4) malfunction of the OMS engines.

3.3.6 Fluid Dump/Vent*

The objective of this phase type is to rid a payload or a Shuttle system of unwanted fluid by dumping or venting it overboard. Such events may be inhbited during certain flight intervals to prevent (1) contamination of payloads, (2) the generation of spurious optical data by the reflection of sunlight from free-floating crystals in the vicinity of the Shuttle, or (3) trajectory perturbations resulting from small translational forces that might be produced in the venting process. The phase begins with whatever preparations are necessary specifically for and immediately before the dump or venting process. This conceivably might include a rotational maneuver to avoid trajectory perturbations in a critical direction, or to insolate the fluid orifice and prevent blockage by freezing. The phase ends after venting has been terminated and the induced "atmosphere" and/or crystal cloud in the vicinity of the Shuttle has dissipated.

3.4 QUATERNARY PHASES

3.4.1 Rotational Maneuver

The objective of a rotational maneuver phase is to attain, by means of appropriate RCS thruster firings, a predetermined Shuttle attitude or rotational rate in relation to a specified coordinate system. This does not include the small corrective firings necessary to maintain an established attitude or rotational rate. Thruster firings may be controlled manually by the flight crew or automatically by the onboard computer. The length of the phase corresponds to the time interval required to stabilize the Shuttle in the desired attitude or rotational mode.

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*This phase type pertains to major fluid expulsion events. There may be minor venting activities which are not amenable to scheduling or which are too insignificant to warrant scheduling.

3.4.2 Inertial Attitude Hold

The objective of this phase type is to satisfy some flight requirement that necessitates the maintenance of a specified inertial attitude. RCS thrusters, usually controlled by an onboard computer, are fired as necessary to maintain the inertial attitude within prescribed tolerances. The phase begins when the Shuttle has been stabilized at the desired attitude. It ends when the appropriate flight requirement has been satisfied and maintenance of the inertial attitude is no longer necessary. Typical flight requirements for this phase type include the maintenance of an inertial attitude during a rendezvous braking phase, and immediately before OMS engine ignition during a translational maneuver phase.

3.4.3 Local Vertical Attitude Hold

The objective of this phase type is to satisfy some flight requirement that necessitates the maintenance of a specified attitude in relation to a local-vertical coordinate system. RCS thrusters, usually controlled by an onboard computer, are fired as necessary to maintain the local-vertical attitude within prescribed tolerances. The phase begins when the Shuttle has been stabilized at the desired attitude. It ends when the appropriate flight requirement has been satisfied and maintenance of the local-vertical attitude is no longer necessary. Typical flight requirements for this phase type include the maintenance of a local-vertical attitude hold to permit the acquisition of earth resources data, or to minimize aerodynamic drag.

3.4.4 Target Tracking

The objective of a target tracking phase is to satisfy some flight requirement that necessitates the maintenance of a Shuttle attitude in relation to the appropriate line of sight which will permit a specified target to be observed visually by the flight crew or tracked by a directional antenna or sensor. The target may be a ground site, a celestial body, or an earth satellite. RCS thrusters, controlled manually by the flight crew or automatically by an onboard computer (possibly using feedback from the appropriate sensor), are fired to maintain or change attitude as required. The phase begins when the Shuttle begins maneuvering to an attitude that will permit the target to be tracked. It ends when the appropriate flight requirement is satisfied and target tracking is no longer necessary. Typical flight requirements for target tracking include relative orbit determination, communication via the TDRS, and orbital reconnaissance of a specific geographic site.

3.4.5 Thermal Conditioning

The objective of a thermal conditioning phase is to attain a desired temperature distribution in the airframe of the Shuttle by means of an attitude schedule designed to control insolation and thermal radiation from the exterior surfaces. This usually requires the use of RCS thrusters to establish and maintain an angular rate about a preferred axis. The phase begins with the establishment of the necessary rotation, and ends when sufficient time has elapsed for airframe temperatures to stabilize. Typically, such phases are required shortly before atmospheric entry. They may be required also after long attitude-hold phases to dissipate the thermal energy of "hot spots" in the airframe.

3.4.6 Attitude Drift

The objective of this phase type is to satisfy some flight requirement that necessitates complete inhibition of all RCS thrusters. The duration of the phase corresponds to the length of time in which RCS thruster firings are inhibited. An attitude drift may be required prior to the release of certain payloads to allow the dissipation of oscillations in the payload-RMS-Shuttle configuration, or to conserve propellant in contingency situations.

3.4.7 Powered Flight Steering

The objective of this phase is to control thrust direction during an OMS burn to permit nulling of the velocity-to-be-gained vector. The phase begins with OMS ignition and ends with OMS thrust termination.

4. FLIGHT PHASE/ACTIVITY CORRELATIONS

As an ideal goal, it would be desirable to structure the standard flight phase classification system in such a manner that all important activity schedules could be defined simply by identifying the phases that comprise the total flight profile. In view of the complexities of Shuttle orbital operations, it is not likely that any such ideal system ever could be devised. Even to approach such an ideal requires the selection of some unique, universal point of focus for the coordination of flight activities. In this proposed system, the standard phase definitions are focused on maneuvering the Shuttle Orbiter vehicle. This choice of focus seems to be logical because:

a) there is one and only one Orbiter vehicle associated with any given flight profile, and

b) it can be doing only one thing at a time in the way of maneuvering.

It is recognized that there are many very important categories of flight activity (including, of course, those cited in the last two paragraphs of Section 2) that are not represented by specific phase types in the classification system which has been outlined. Figure 2 is a schematic illustration of how such activities are related to the proposed flight phase structure. The formulation of detailed flight activity schedules is expected to be a formidable problem in the high flight frequency environment of the Shuttle operational era. This problem can be alleviated by expanding and refining the provisional phase definition in Section 3 to include, if not step-by-step operational sequences, at least the essential requirements for all pertinent activity areas. Although no system of standard phases can be expected to automatically produce complete detailed definitions of all the many activity timelines pertinent to a Shuttle flight, the one that has been proposed here can provide an effective basis for simplifying the integration of the various timelines into a total flight plan.

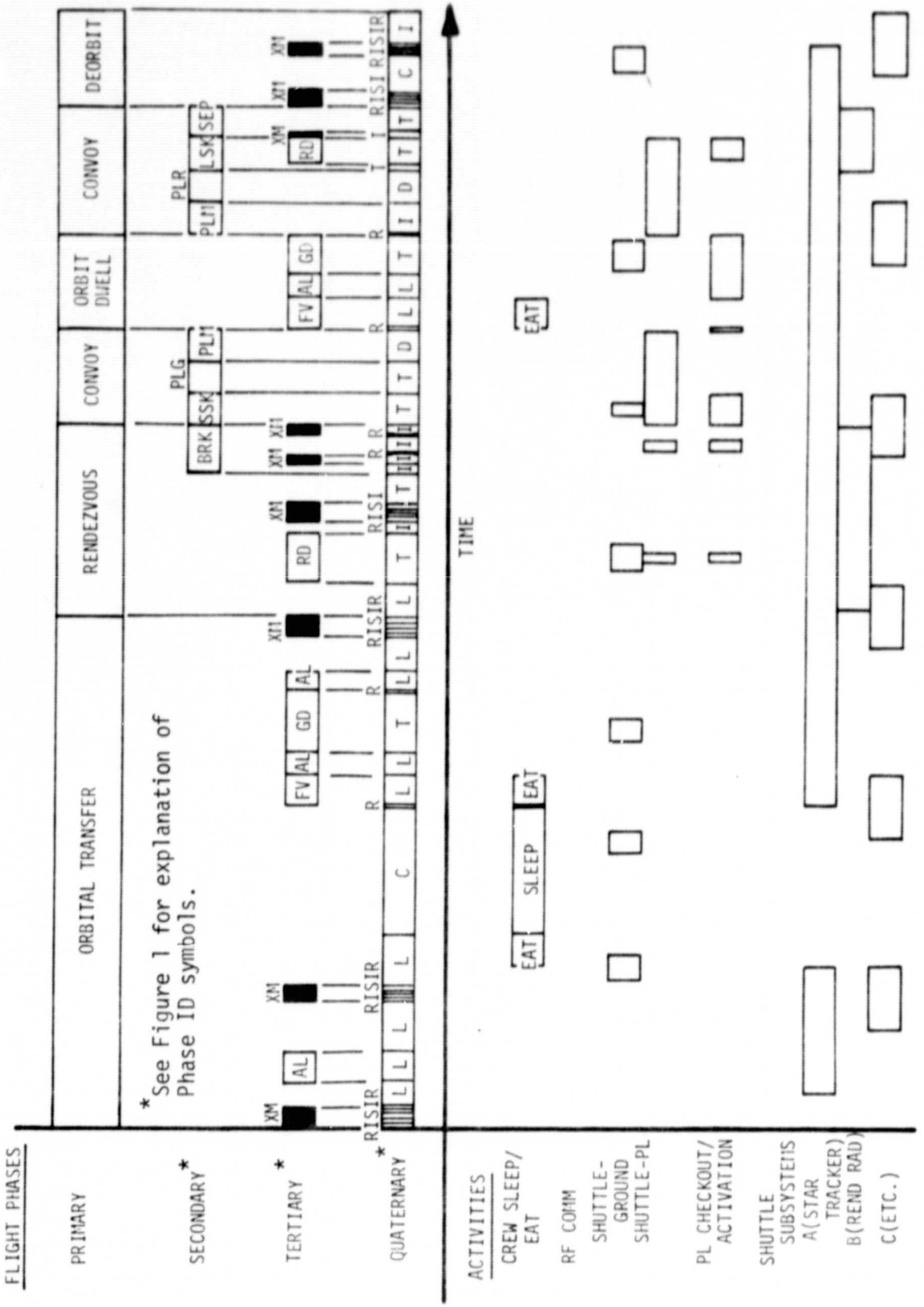

Figure 2. Flight Phase/Activity Correlations

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