J. Oberg // Sep 4, 1990 // Final Draft

THE ROOTS OF RENDEZVOUS

The world's first orbital rendezvous occurred a quarter century ago (December 15, 1965), and the operation has been repeated more than a hundred and fifty times since then, with different vehicles, with varying degrees of success, with various (or no) navigation sensors, and around different worlds. "Rendezvous" has been the key spaceflight operation which enabled the moon landing, the establishment of space stations, and the repair/refurbishment/retrieval of satellites.

All of this was possible only because of foundations laid down in the previous decades by spaceflight theorists and engineers. The conceptual barriers were often more difficult to overcome than the practical ones.

Very early in the development of spaceflight speculations (in the 1920's), theorists laid down plans for earth-orbiting space platforms. These platforms would be launch points for new probes or would be construction sites for bigger space objects, and they would be visited and supplied from Earth by means of new launchings. "Rendezvous" would occur routinely.

Yet little consideration was given to how this would be done in practice. Planar launch windows were recognized (the characteristic sinusoidal groundtrack was easy to predict), and inter-orbit trajectories (such as the Hohmann transfer) were planned. But what little thinking there was on controlling such maneuvers merely assumed that a ship would be sent on a pre-planned trajectory (in-plane and on-time), then some tracking might later occur, and the crew would null course deviations while gradually reducing the closing rate. The actual effect of orbital mechanics on relative motion was not appreciated then, and actually would not be until real manned orbital maneuvering was first attempted.

A conceptual revolution in the importance of rendezvous occurred in 1948 when several members of the British Interplanetary Society (BIS) worked out the theory of "orbital staging". Flights to the Moon, for example, could occur even without an intermediate refuelling base (one of the main uses of the early space station concepts) if the main ship could rendezvous with other vehicles at various stages en route. A plan by Harry Ross called for three launchings into low earth orbit, where one ship was refuelled from the other two. The lunar ship went into lunar orbit where it detached a large fuel tank, left it in orbit, and then descended to the lunar surface (the BIS moonship was a squat four-legged spidery-looking structure). After return to lunar orbit the manned ship rendezvoused with the fuel tank, transferred the fuel, and used it for the earth-bound burn. Re-entry and landing was not well thought out.

This concept paralleled one developed in the 1920's by a Russian spaceflight enthusiast named Yuri Kondratyuk. He envisaged a manned lunar expedition in which a spaceship in lunar orbit dispatched a small landing craft to the surface and back. He (and, later but independently, Ross, and later even others) easily calculated the major weight savings in not having to bring the return fuel and structure down to the lunar surface and then back up. Kondratyuk's paper which outlines this scheme was published in 1935 but was so far ahead of his time it was overlooked even in his own country. No doubt he would have expanded and improved his concept but he was killed during World War II. His pioneering role was only realized decades later.

Astonishingly, there were few subsequent major changes to the Kondratyuk/Ross ideas for manned lunar missions using lunar orbit rendezvous. Ross had not considered that the highly-varying mass of his lunar vehicle might call for using different sized engines and hence entirely different vehicles (although the famous BIS lunar lander discarded excess mass on the lunar surface and did use different engines for landing and ascent). The heavy earth-entry hardware (heat shield and parachutes), which increased further the advantage of lunar orbit staging, was not yet fully appreciated.

But the weight-saving numbers were clear and by 1950 the worldwide community of spaceflight theorists had accepted the central importance of rendezvous (earth orbit, lunar orbit, or both) for space missions even apart from use in visiting space stations. ~~By 1951,~~ the operation was even being called "rendezvous" (Russ, in 1948).

Contemporary discussions of operational concepts, however, still showed a lack of appreciation of the highly-dynamic nature of proximity operations and relative motion of close-orbiting objects. There was published concern over space stations becoming surrounded by clouds of cast-off debris which would orbit nearby indefinitely. Refuelling spaceships were drawn floating side by side like ships at sea or formation-flying aircraft. There was as yet no theoretical bases of relative motion effects of orbital mechanics forces which we now know would rapidly separate such objects.

When NASA was assigned the lunar landing mission in 1959-1960, it quickly recapitulated the theoretical evolution of manned lunar mission design which had occurred among the pre-spaceflight enthusiasts from the 1920's through the 1950's. Early plans for direct lunar missions (during which rendezvous was mentioned only in passing as a means of space station support) rapidly evolved in the same direction, compelled by the same arithmetic. Dr. John Houbolt (director of the rendezvous studies group at NASA's Langley Research Center) is often simplistically credited with inventing the idea of lunar orbit rendezvous, but he always made clear that he was developing already-existing concepts from the pre-Apollo-era context, and he was merely the concept's most effective advocate. As such he played a crucial role, because intellectual inertia among the space engineers created enormous resistence to such a superficially hare-brained idea as lunar orbit rendezvous. But Houbolt stuck to his guns (or actually to his numbers), and the other lunar mission techniques developed problems of their own, and the NASA space community gradually shifted its previous opinions.

Meanwhile, the first US space rendezvous program was actually being pushed by the Defense Department. Called "SAINT", for Satellite Interceptor, it called for an Atlas-Agena-launched robot craft to perform a rendezvous with a passive target (presumably foreign. possibly hostile) and conduct an inspection. Serious operational problems were uncovered and alternative ground-based inspection techniques were developed, and by 1962 the project was cancelled. However, some early research and some key personnel transfers to NASA helped prepare the ground for NASA's own follow-on program.

By 1962 NASA had settled on lunar orbit rendezvous as the safest, cheapest, quickest way to accomplish the manned lunar landing. "Rendezvous" would have to work. By then, engineering analysis showed that actually accomplishing "formation flying" with real-world tracking systems, buildable on-board navigation and propulsion systems, and existing computational facilities would be a genuine challenge, and the Gemini program was created and inserted between the in-progress Mercury program and the already-announced Apollo program. Proving out techniques of orbital rendezvous was one of three major announced goals, but it was also "first among equals": rendezvous had to be made "do-able" if the lunar landing (and, later, space stations) was to be accomplished.

The spaceflight rendezvous of direct current interest is low Earth orbit, zero-zero (zero closing rate at zero range). Other categories of space rendezvous may involve near-Earth high-speed rendezvous (say, for fly-by inspection or interception), deep-space rendezvous (say, for modules of a Mars-bound vehicle), planetary surface rendezvous (to get home again), and others. These, too, were being studied by early theorists.

To perform a rendezvous, a vehicle must be able to carry out a number of specific functions. It must be able to navigate (determine its relative position with respect to its target, using both local and remote sensors and either local or remote state vector computation, both at the present time and in the near future), to within "reasonable" uncertainty. It must be able to perform guidance (determine how it needs to change its current state vector in order to place itself at a desired future relative position). It must be able to control its motion, using rockets or wings or shock attenuators or similar mechanisms, and must be able to monitor such changes to determine they are what was required. And in practice it must do so with techniques that can both tolerate the loss of some capabilities (navigation, guidance, control) while allowing backup capabilities to permit the completion of the rendezvous, and also can tolerate unanticipated schedule changes (mostly delays) during the rendezvous.

Bits and pieces of these functions were introduced piecemeal during early space missions. From the start (1961), ground-based navigation had to be adequate for gross maneuvers such as entry, and it soon became adequate for most rendezvous maneuvers as well. Judging nearby relative motion was evaluated by a tracking balloon ejected from the second manned Mercury flight (1962). Two separate Soviet manned vehicles were placed in parallel orbits to test insertion precision, ship-to-ship communications, and transponder ranging. Orbital maneuvers were conducted to determine how precisely a desired new trajectory could be achieved in practice (Soviet unmanned Polyot, 1963; US manned Gemini, 1965).

The United States was on the threshold of orbital rendezvous by 1965 . Although it was realized that propagation of orbital motion, particularly relative motion, was an extremely difficult and "unearthly" pursuit, this point was not driven home until the GEMINI-IV mission's embarrassing fiasco of attempting stationkeeping with the booster. It failed because the pilot (with only one pre-flight rendezvous simulation) attempted to use jet fighter techniques to close with the target rather than proper orbital mechanics. As a result of this harmless humiliation, astronauts and operators at last focussed their attentions on carrying out the rendezvous process. The rest is history.