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Landing Profile Development During the Early Shuttle Program

Karol J. Bobko

I was asked to speak about my experiences as an astronaut during the early Shuttle program. There were many challenging and exciting things that I participated in during the Shuttle program but the item I believe is most appropriate for this audience is the development of the landing trajectory for both manual and automatic landings of the Space Shuttle.

LANDING SLIDE

When the Shuttle [illegible]ed there were thoughts of putting engines on the vehicle and having it land much the same as a modern jet aircraft would land. Unfortunately, putting engines on the Shuttle had tremendous performance and engineering costs. The engines and their systems were heavy and complex and had to be protected from the harsh environments they would encounter during a Shuttle mission.

BURAN SLIDE

The Russians did ran spacecraft, their copy of the Shuttle, but they only used them for the flight test phase. The Russian Buran was also more streamlined than the Shuttle since it did not have the main engines mounted on the rear of the Buran. The Buran's main engines were mounted on the aft of the main fuel tank. That meant they could not reuse the main engines, but it also meant the aft end of the Buran would be more like the Shuttle configuration used for the first three approach and landing test flights and the vehicle would have better glide characteristics.

SHUTTLE WITH
TAILCONE

The Russians didn’t use air breathing engines on the orbital flight the Buran flew.

Without air breathing engines on the Shuttle a very different type of approach was required. The Shuttle had very short wings and a terrible glide capability. But aircraft with minimum glide capability had been flown at the Air Force Flight Test Center for a number of years. The X-15, for example, first flew in June of 1959.

X-15

When I attended t[illegible] 1965 we were regularly doing what was called an L/D approach in the F-104. L/D stands for left to drag ratio. That number indicates how well the vehicle will glide.

Those approaches were very dynamic and left little margin for any error. As a matter of fact there was an accident in one of the L/D approaches and one of the pilots was killed. But there were 199 X-15 flights and probably thousands of other flights where L/D approaches were made before the Shuttle flew. The question was how do you develop a landing procedure that can be automated and will work in an operational program from one where you are landing on a lake bed with miles of lake bed runway.

A test pilot from Ames Research Center near San Francisco, by the name of Fred Drinkwater, worked to develop that approach procedure and the approaches are called Drinkwater approaches.

Fred Drinkwater flew a specially equipped Convair CV-990 aircraft from Moffett Field, California to Edwards Air

Force Base, California, to refine steep and final aircraft approaches to possibly be used for a space shuttle vehicle to land on a hard surface runway. The Convair aircraft had pilot flight instruments that would be similar to those in the space shuttle Enterprise being manufactured by Rockwell International, the company that had won the competitive U.S. Government bid to build the space shuttle in Palmdale, California.

With precise and refined testing of his landing technique, test pilot Fred Drinkwater's two-segment approach for landing consisted of a steep segment starting at 25,000 feet altitude and pointed at a target spot a mile short of the runway. This was followed by a three-degree path to the touchdown point on the runway. This steep, unusual profile for landing became widely known in the test pilot community as the "Drinkwater approach" and later would be used by space shuttle crews to land orbiter vehicles; known as today's space shuttle.

Drinkwater's test was November 1, 1972.

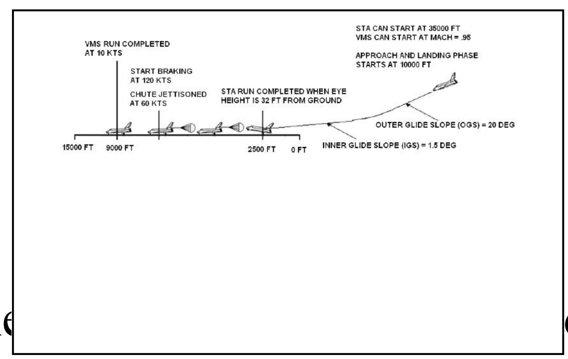
It is interesting to note that President Nixon announced the Space Shuttle on January 5, 1972 and the contract to build the Space Shuttle orbiter was signed on August 9, 1972.

There is a very dynamic landing profile. Things happen quickly. I remember a flight in the back seat of an F-104 flying a Drinkwater approach on instruments under the hood.

F-104

Bill Dana was in observer. We had successfully aches and Bill said to me "Bo, at the preflare Point why don't you put the hood back and go ahead and land the aircraft". That sounded good so that is what I attempted to do. At the preflare point I pushed the hood back and attempted to get oriented. Before that happened Bill took control of the aircraft. In just those few seconds that I was pushing back the hood and trying to get oriented I had gotten too low for Bill's comfort. And Bill is no sissy; he had flown 16 X-15 flights.

Well, what does the Drinkwater approach, or the Shuttle approach look like?



It is a two segm d at about 10,000 ft. above the runway and about 7 miles short of the touchdown point. This steep segment is on a 20° glide path and flown at 300 knots. That glide slope and air speed requires about 50% speed brake assuming there is no wind. If there is a wind, or if there is a displacement that needs to be corrected, the speed brakes are re-positioned. If you have a tailwind the speed breaks are more than 50% open. If it is a headwind they will be less than 50%.

At about 2,000 ft. the pilot starts a pull out to merge with a 1.5° glide slope. You may ask why a 1-1/2° glide slope when most aircraft fly a 3° glide slope. The reason is that you get to the glide slope at about 300 knots and if it were a 3° glide slope you would have a sink rate more than twice that of a jet aircraft that flys at a slower speed (as an example a 747 flys final at about 150 knots).

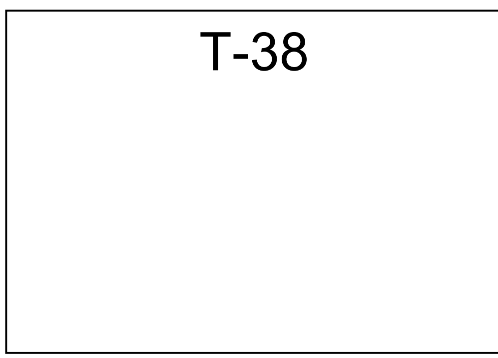
In designing the Shuttle landing approach we had the challenge of making the approach as comfortable as possible for the pilots and at the same time being an approach the automatic system could personably perform. In the case of the 1.5° vs. 3°glide slope the pilots would have liked an even shallower angle, but the shallower angle would have caused problems with reception of signals of the MSBLS (Microwave Scanning Beam Landing System). The 1-1/2 glide slope was a compromise between the manual and automatic system.

In the development of the automatic system I tried to keep three principles in mind to allow the manual and automatic systems to be compatible:

1) the automatic system had to be reasonable,
2) the automatic system had to be predictable, and
3) the trajectory flown by the automatic system had to allow the pilot to take over at anytime.

Let me talk about each of these items in a little more detail. The first is the system has to be reasonable. Basically that means the system can't scare you during its execution. If you were designing a system that was to park your car in the garage automatically you won't want it to approach the garage at 60 miles per hour and then put the brakes on at the last second.

The second is the system has to be predictable. If a pilot is going to monitor the automatic system he or she is going to want to know what the system will do. And finally, the pilot should be able to take over if things don't appear to be going correctly.



I like to compare file in the time domain with that of a T-38 which I flew at NASA for years. Most instrument landing system approaches have a ceiling and visibility limit of 200 ft. and ½ mile. When I was at NASA we couldn't plan to go anyplace that was expecting a ceiling of less than 300 ft. If you are flying a T-38 the descent rate on final at 300 ft. is about 600 ft. per minute. At 300 ft., therefore, you are about 30 seconds from the ground. If you have set up the approach correctly your attitude, air speed and power settings should all be stable. The runway should be in the wind screen and should be in a constant position – just growing larger.

Compare this with the Shuttle at 30 seconds before touchdown. The Shuttle is at about 300 knots, just starting the preflare from the 20° glide slope at 2,000 ft. The attitude is nose down but must be brought to a nose up attitude for landing. The airspeed must be changed by about 100 knots. At the beginning of the 30 second period the runway is at the upper part of the windscreen, at touchdown it is below the nose. Since the speed will be changing, the effects of any wind will be changing, even if the wind is constant. Remember my story of flying in the back seat of an F-104 with Bill Dana. The last 30 seconds before landing are a very dynamic time.

Once you are on the ground it doesn't mean your problems are over.

SHUTTLE DURING ROLLOUT

The Shuttle h[illegible] the nose is put down the tires are loaded because of the negative angle of attach. The tires are compressed to 1/3 of their profile because of the aerodynamic load. On a normal aircraft the tires would only be compressed to 2/3 of their profile. It would be helpful to put the big elevons up to slow the Shuttle but doing that would load the tires more – so the elevons are put down to unload the gear and tires. In the early Shuttle flights there was no chute, the elevons were down in what was a streamlined position, and the brakes had marginal energy capacity. If you put the brakes on quickly they would fail before you were stopped. You had to wait until the aerodynamics had slowed the Shuttle before you could put on the brakes. What this meant was the Shuttle had no high speed deceleration capability. On a transport you have thrust reversers – on a jet flight there is a drag chute. The Shuttle had to wait for the aerodynamics to slow it down.

Later in the Shuttle program a drag chute was added. That was a great addition. It gave good deceleration at high speed and quickly made the problem a lot more manageable. Thank God for 15,000 foot runways.

One of the items that has made landing the Shuttle easier or monitoring the automatic system is the Heads Up Display or HUD. The HUD made its first flight on the first flight of the Challenger which was STS-6. The flights before didn't have a HUD. I was the pilot on STS-6 and because we didn't know how well the HUD would work we trained without the HUD as much as we trained with the HUD. As it turned out the HUD was a great aid both in landing the Shuttle and in monitoring the auto land.

When you rolled [illegible]00 the virtual runway projected in the HUD showed how well the navigation state agreed with the real world.

If the virtual runway was on top of the real runway the states agreed; if the virtual runway in the HUD was not lined up with the real runway the guidance the automatic system provided was in question. Here you can see the symbology on the HUD. The Velocity Vector symbol predicts where the Shuttle is going; Guidance Diamond indicates where the computer thinks you should go and the other readings show the flight parametric such as altitude, airspeed, descent angle, speed brake position, and radar altitude.

Training for landing the Shuttle was intensive and was accomplished in the Shuttle Training Aircraft (STA), the Shuttle Mission Simulator, and the Vertical Motion Simulator.

STA IN FLIGHT

The STA is a mo[...]t simulates the Shuttle very well. A Shuttle commander probably has 1,000 simulated landings in the STA before he lands the Shuttle.

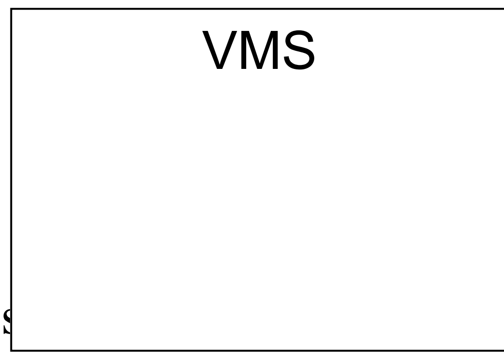
STA INTERIOR

This picture shows the STA interior. You can see the Shuttle "fly by wire" stick on the left side as well as the Shuttle type monitors on the instrument panel. The view outside looks quite good – actually too good. To have the same view as the Shuttle the windows are masked. The STA simulates the approach and landing but it doesn't quite land. It descends to a point where the student astronauts' eye height is the same as it would be in the Shuttle at landing – 32 ft.

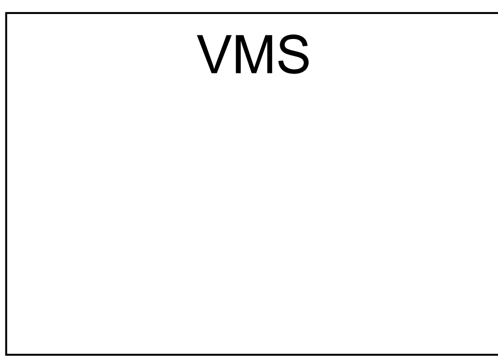
SHUTTLE
COCKPIT

The Shuttle Missi e systems modeled that are rt video clip is of an actual Shuttle cockpit and not of a simulator, but it will give you an idea of the complexity of the Shuttle. This simulator is also on a motion base but one with rather limited travel. Since the Shuttle Training Aircraft can only descent to a 31 foot eye height, and since the

Shuttle Mission Simulator only has limited motion capability that leaves a critical gap in the astronauts training. Even if you could land the Shuttle Training Aircraft would you try to simulate things like a blown tire at 200 MPH? This is where the Vertical Motion Simulator comes in to fill the gap.



The VMS has 60 nd 40 feet of horizontal travel s ynamic motion that may occur in a landing quite well.



This simulator or n used for Shuttle development and oach and Landing Tests. The set of simulators used for Shuttle development and training when used together have been excellent devices to develop and train for a Shuttle landing.

In aviation today many runways have lighting systems that help guide the pilots on their approach to the runway. There was a desire to provide that same type of system for the Shuttle.

The lighting system on the ground provides an external cue to the pilots as to their position with regards to the desired profile. There is one set of lights to define the 1-1/2° glide slope and a second set to define the 20° glide slope. The lights that define the 1.5° glide slope are a bar of lights horizontal to the ground with a bright light positioned in such a manner as to appear on the bar when on the 1.5° glide slope. I had tried a Navy mirror but it just didn't have enough power to be able to see it at the range desired. These lights are called the Ball-Bar.

The lights that define the 20° glide slope are a set of PAPI (Precision Approved Path Indicator) lights set up in a manner to define the 20° glide slope. These are the same type of lights used at many airports except they are set up for a much steeper approach.

The Shuttle also has a requirement to perform night launches and landings. If you are going and coming from a Space Station you must essentially launch into the orbital plane of the station. That means the Shuttle must launch and land at night.

Remember, I spoke of the fact that the orbiter is going about twice as fast as a normal transport when it gets into the 1.5° glide slope and that the Shuttle's attitude must change by 30° over the last 30 seconds of flight? There is also the fact that the gear is not put down until you are at a couple of hundred feet of altitude. What this means is that if you put a landing light system on the orbiter it would have to be very powerful, complicated, and would only be useful for a few seconds.

Considering all this it was decided to put the lights on the ground and not on the orbiter. A set of powerful search lights is placed off the approach end of the runway positioned to illuminate the runway. This has worked well for the night landings that have been done.

Let me go back to the time when the gear is put down. It is just a few seconds before landing – why so late. Well remember, you can't go around so the gear has to come down before you land. The gear is normally put down by hydraulics but if that doesn't work pyros unlock it automatically and the airstream will bring it down. Let's say you put it down at 10,000 feet. That would add more drag to the orbiter and you would have to fly a steeper glide slope to maintain airspeed and that only gives you another minute or so. The reasonable thing to do is to put the gear down just before landing as we now do.

One thing that is on the orbiter that is rather superfluous is the set of gear down lights. Once you have pressed the gear down button there is nothing else to do. If you are watching the gear down lights and they don't come on you will probably die tensed up.

Auto land

Closing